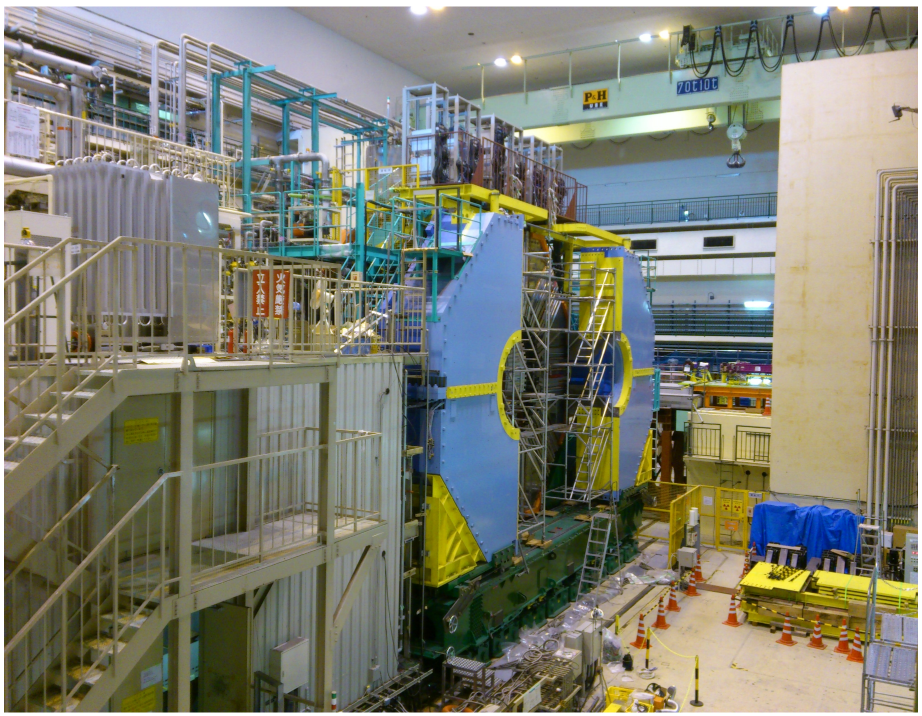
Existing and future experimental possibilities in hadron spectroscopy

Focus on heavy quarks.

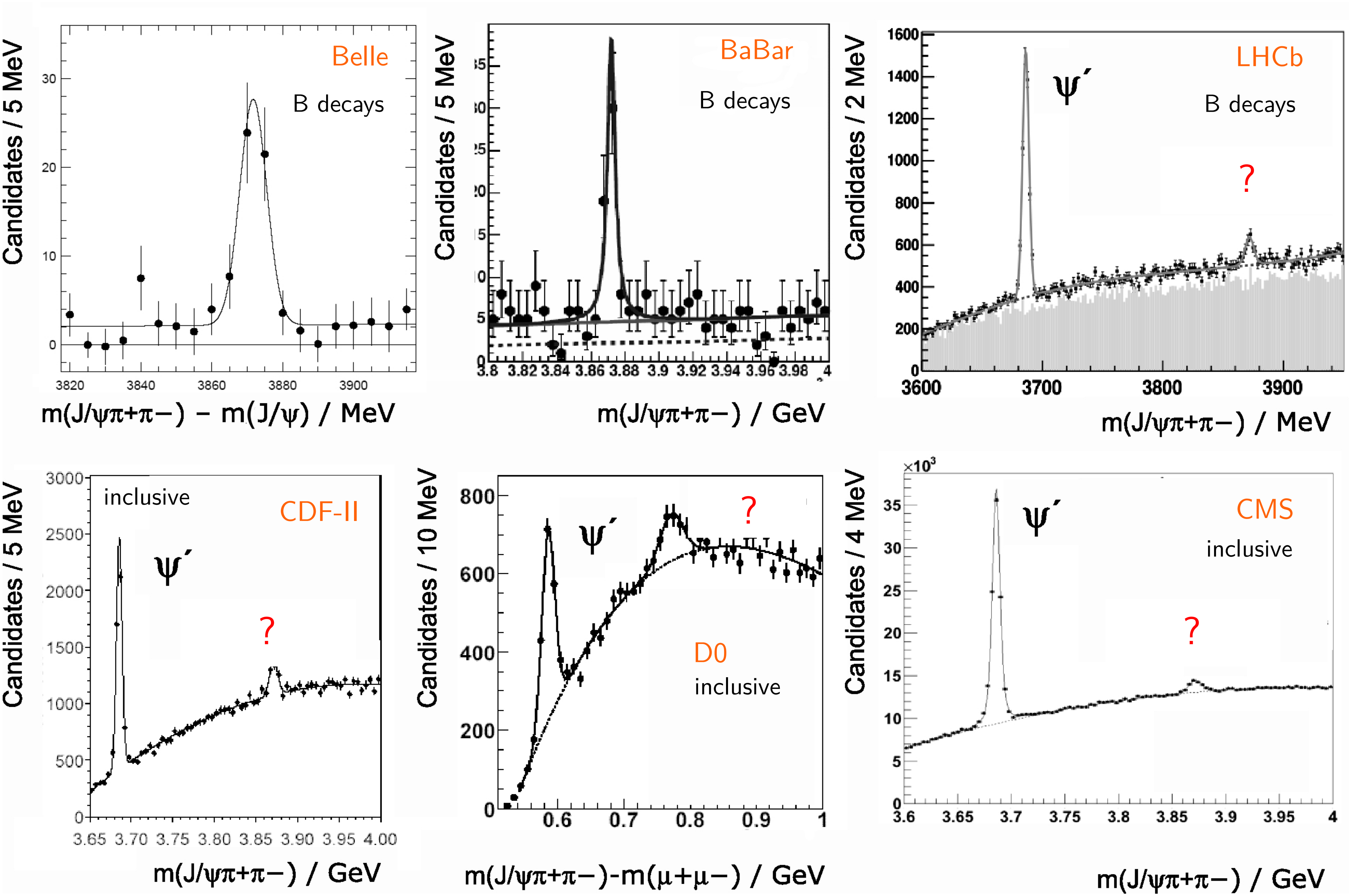
Jens Sören Lange
Justus-Liebig-Universität Giessen
ATHOS 4 / PWA 9
Bad Honnef, 13.–17.03.2017



Composition with Yellow, Blue and Red
Piet Mondrian
1937–42

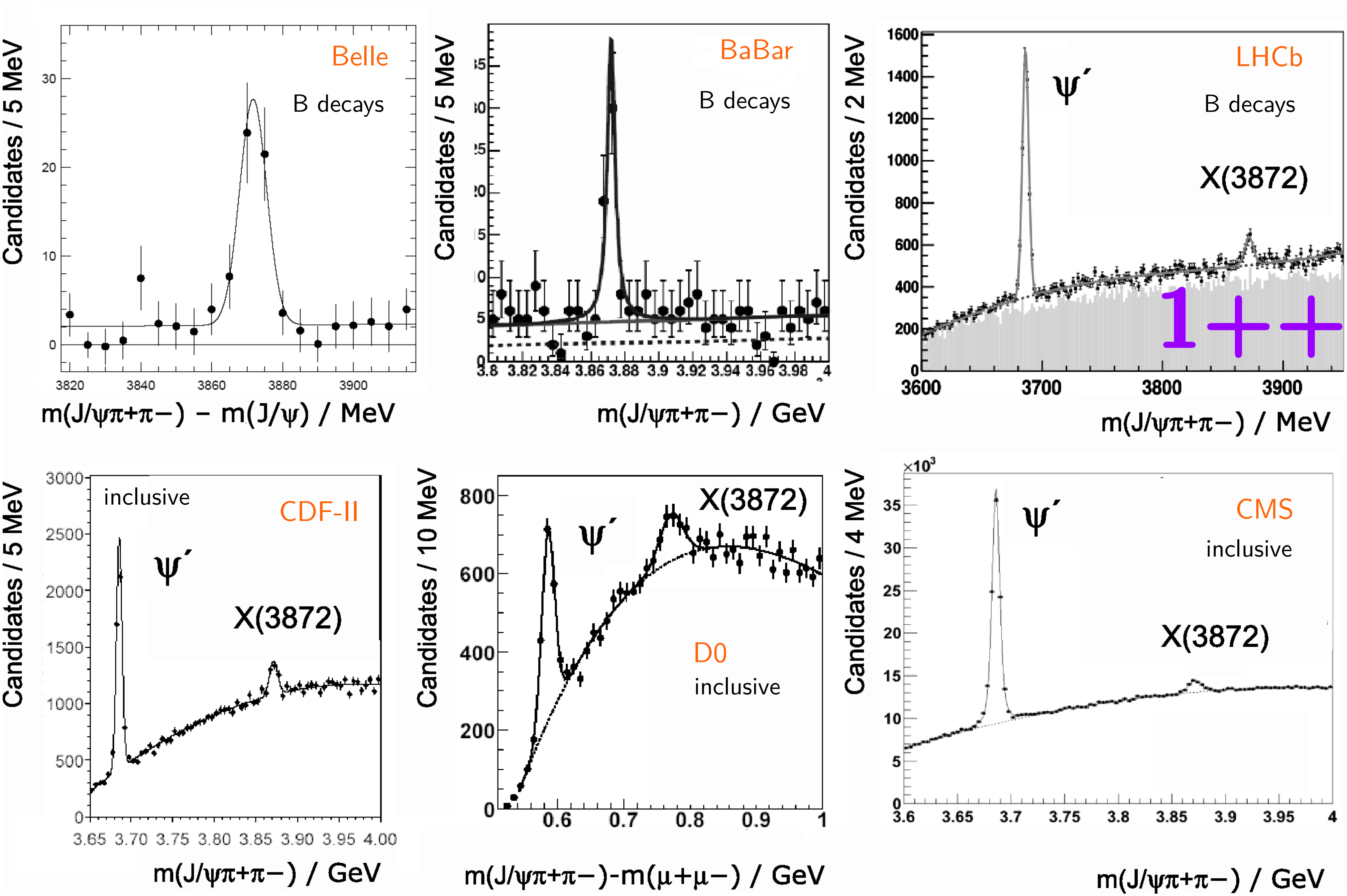
REVIEW OF XYZ STATES

?

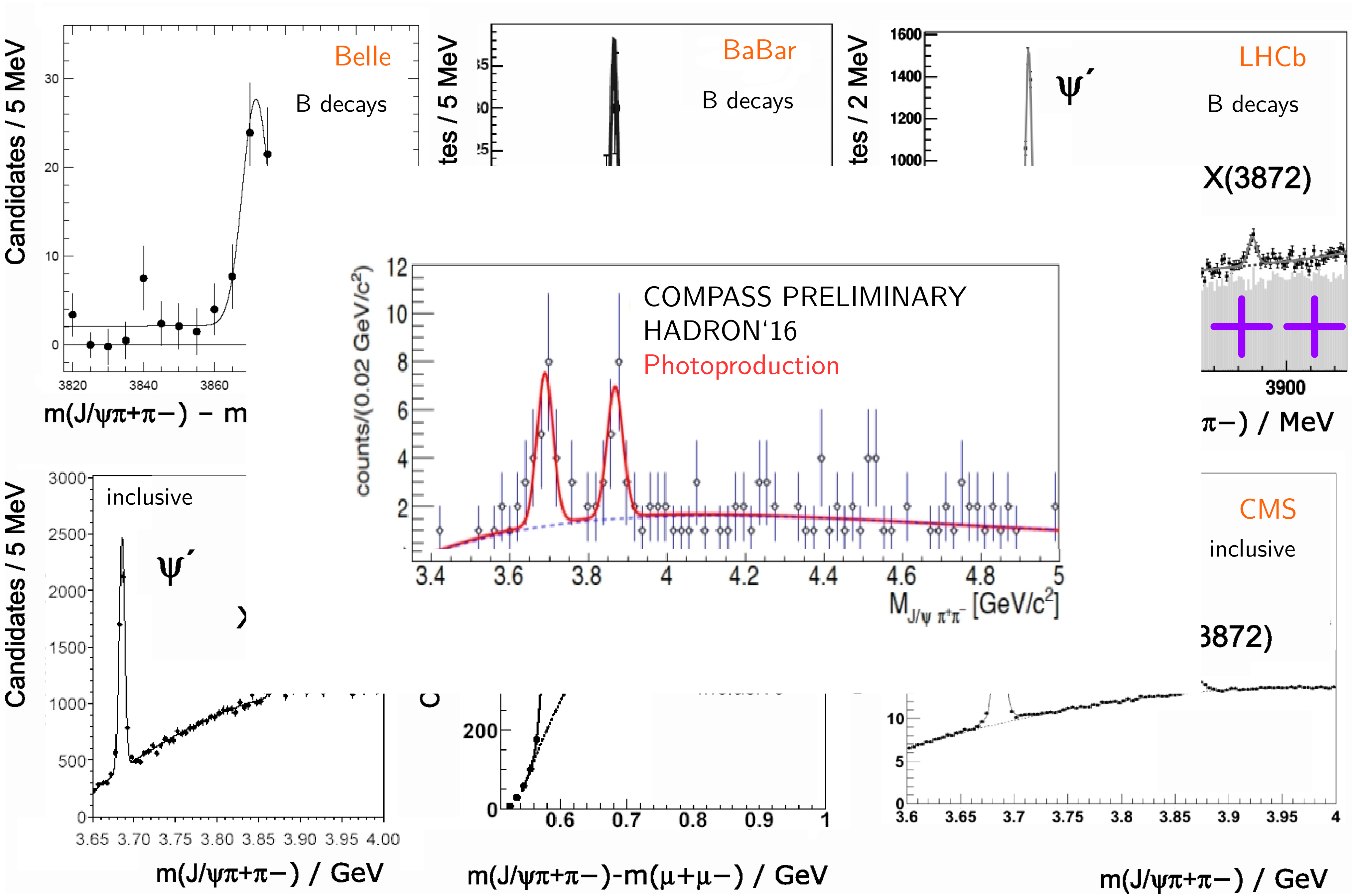


Belle
B decays
Candidates / 5 MeV
m(J/ψπ+π−) − m(J/ψ) / MeV
BaBar
B decays
Candidates / 5 MeV
m(J/ψπ+π−) / GeV
LHCb
ψ´
B decays
?
Candidates / 2 MeV
m(J/ψπ+π−) / MeV
inclusive
CDF-II
ψ´
?
Candidates / 5 MeV
m(J/ψπ+π−) / GeV
ψ´
?
D0
inclusive
Candidates / 10 MeV
m(J/ψπ+π−)-m(μ+μ−) / GeV
ψ´
CMS
inclusive
?
Candidates / 4 MeV
m(J/ψπ+π−) / GeV

X(3872)


Belle
B decays
Candidates / 5 MeV
m(J/ψπ+π−) − m(J/ψ) / MeV
BaBar
B decays
Candidates / 5 MeV
m(J/ψπ+π−) / GeV
LHCb
ψ´
B decays
X(3872)
1++
Candidates / 2 MeV
m(J/ψπ+π−) / MeV
inclusive
CDF-II
ψ´
X(3872)
Candidates / 5 MeV
m(J/ψπ+π−) / GeV
X(3872)
ψ´
D0
inclusive
Candidates / 10 MeV
m(J/ψπ+π−)-m(μ+μ−) / GeV
ψ´
CMS
inclusive
X(3872)
Candidates / 4 MeV
m(J/ψπ+π−) / GeV

X(3872)


Belle
B decays
Candidates / 5 MeV
m(J/ψπ+π−) − m
BaBar
B decays
LHCb
B decays
ψ´
X(3872)
MeV
COMPASS PRELIMINARY
HADRON'16
Photoproduction
counts/(0.02 GeV/c²)
M_{J/ψ π+π−} [GeV/c²]
inclusive
ψ´
m(J/ψπ+π−) / GeV
m(J/ψπ+π−)-m(μ+μ−) / GeV
CMS
inclusive
m(J/ψπ+π−) / GeV

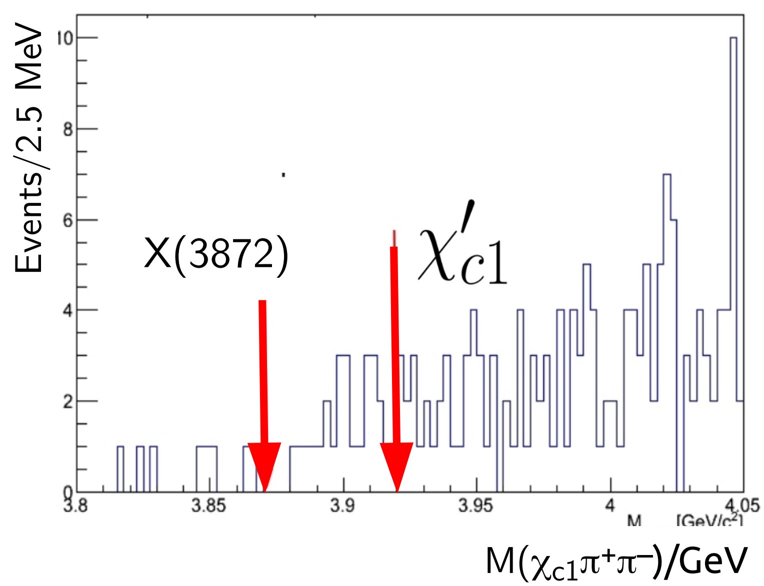
X(3872)

- at $D\overline{D}^*$ threshold
  $E_B = 160 \pm 330$ keV
  but no threshold effect
  $\Gamma \leq 1.2$ MeV $\rightarrow$ too narrow ($\sim$10 MeV)
  Bugg, J. Phys. G35(2008)075005
- but $D\overline{D}^*$ decays dominant
  (factor $\sim$10 larger than other decays)
  $\rightarrow$ molecule ?
- violates isospin
  $\mathcal{B}(X(3872) \rightarrow J/\psi\rho)$
  factor $\sim 10^2$ too large
- $J^{PC} = 1^{++}$, predicted nearby χ_{c1}'
  Barnes et al., Phys. Rev. D72(2005)054026
  $\rightarrow$ mass $\geq$50 MeV higher
  $\rightarrow$ width factor $\geq$100 larger
  no admixture observed

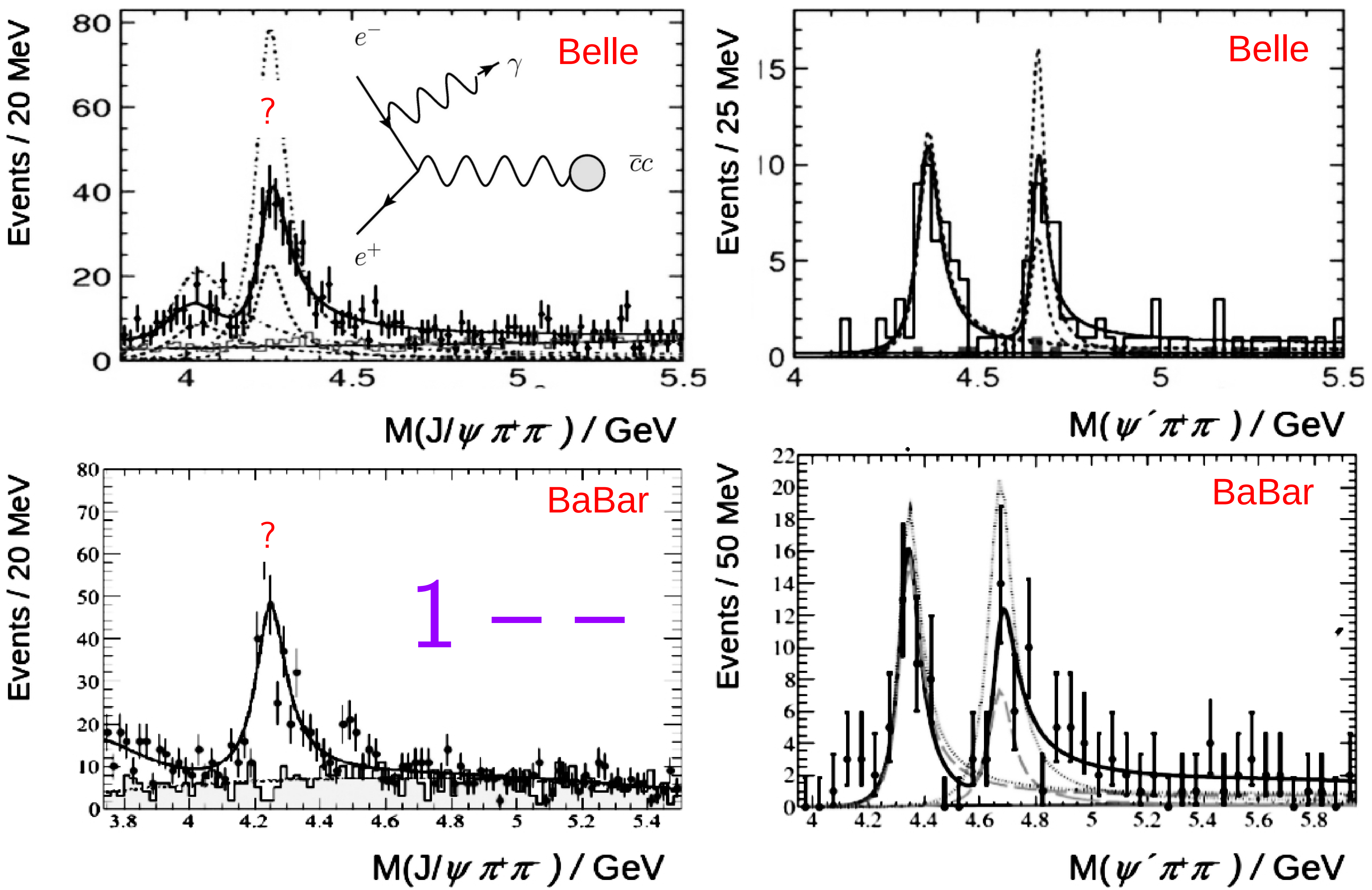
$$|X(3872)> = \cancel{c_1|c\bar{c}>} + c_2|\overline{D}^0 D^{0*}>$$

pure charmonium + „molecule“

Belle, Phys. Rev. D 93, 052016 (2016)
full data set

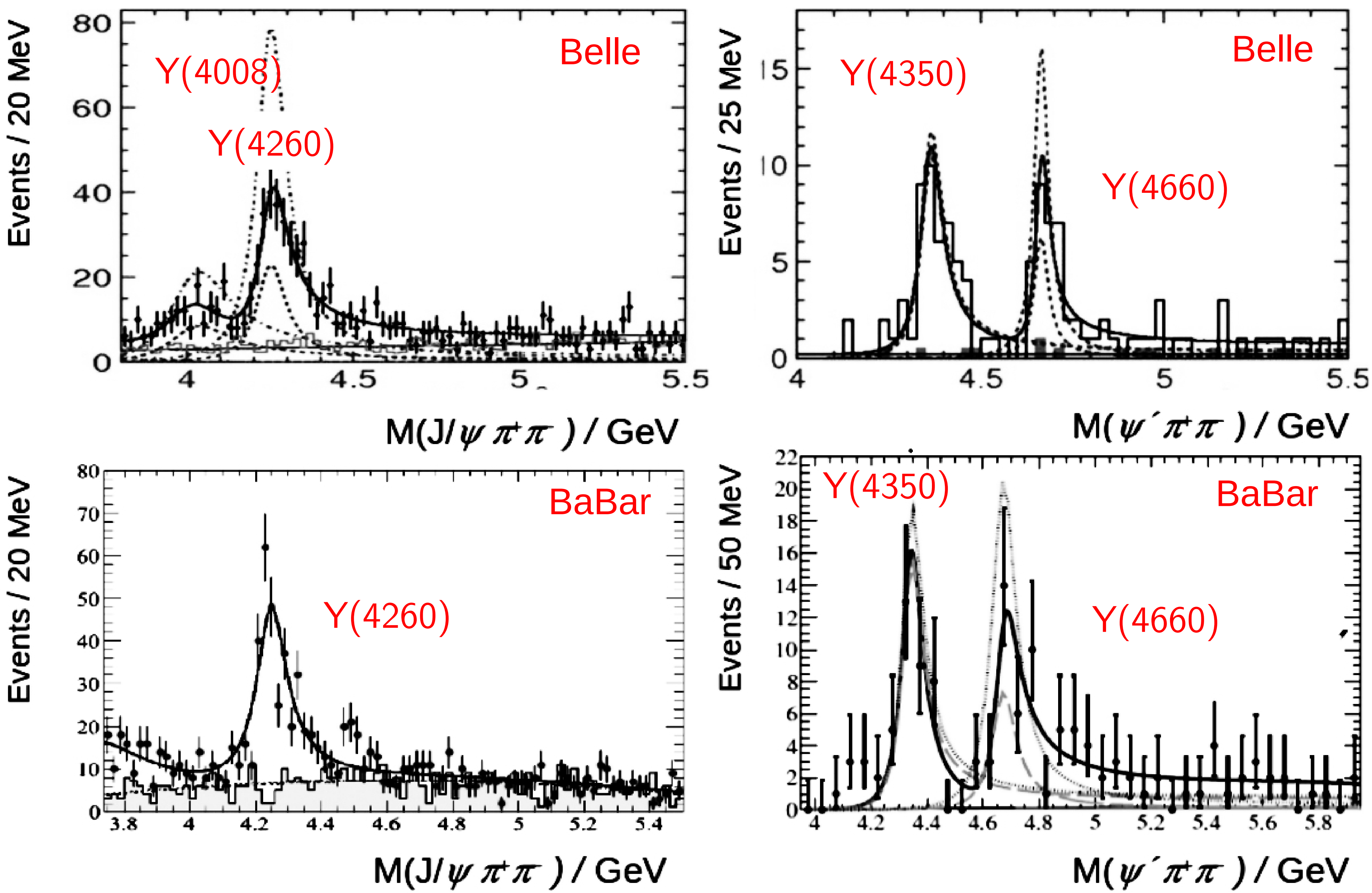


?



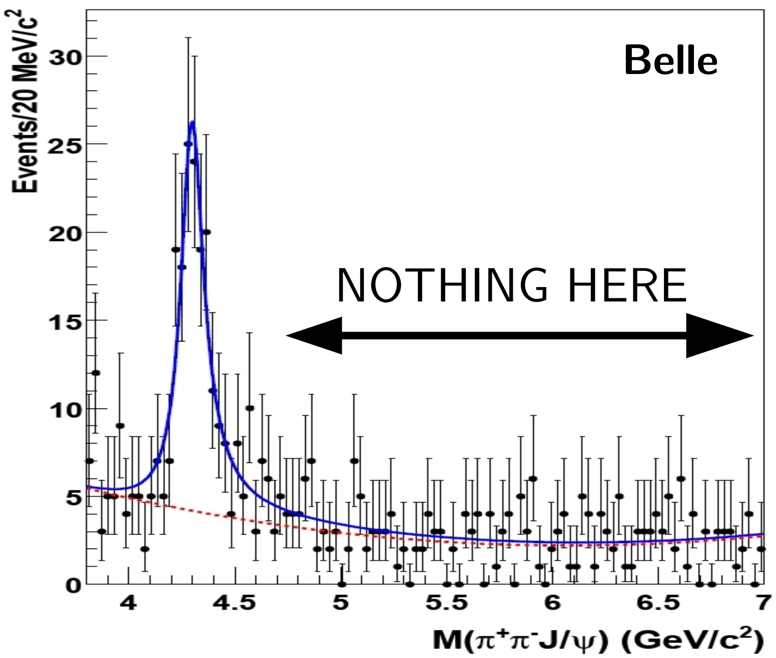
Belle
Events / 20 MeV
M(J/ψ π⁺π⁻) / GeV
e⁻
e⁺
γ
c̄c
?
Belle
Events / 25 MeV
M(ψ′ π⁺π⁻) / GeV
BaBar
Events / 20 MeV
M(J/ψ π⁺π⁻) / GeV
?
1 − −
BaBar
Events / 50 MeV
M(ψ′ π⁺π⁻) / GeV

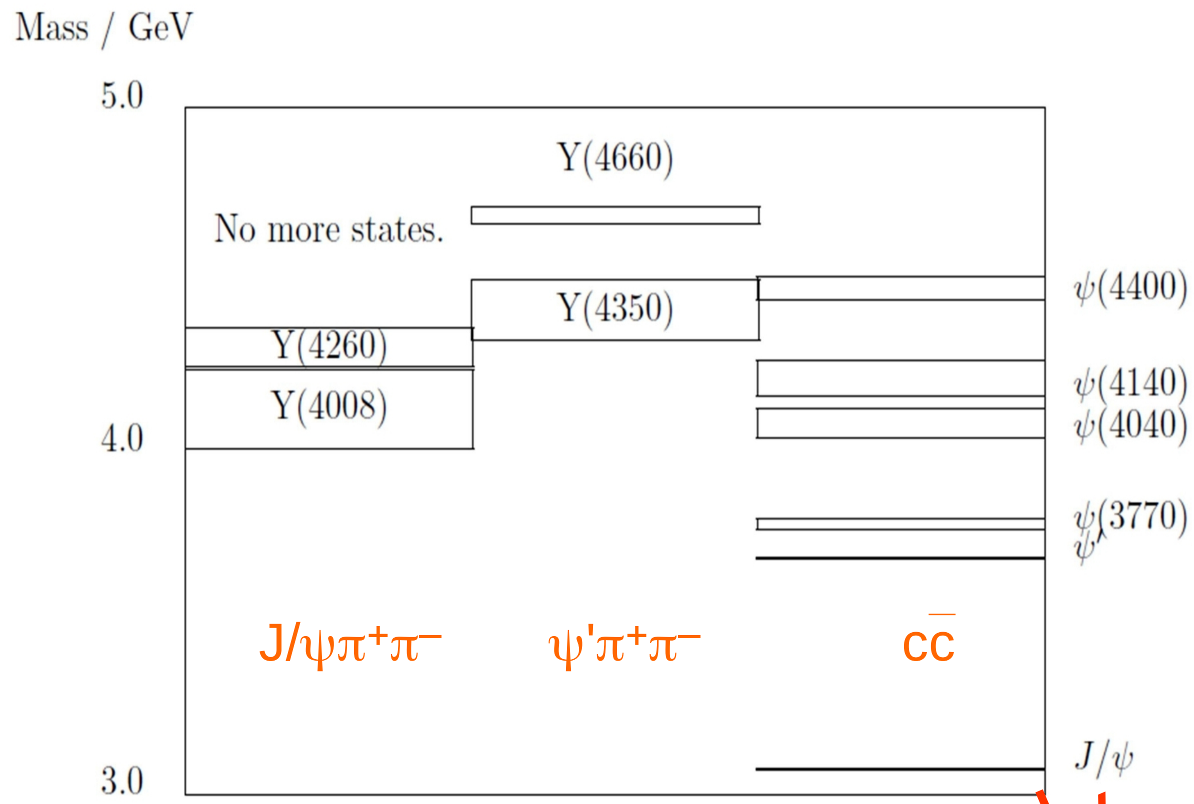
Y STATES



Belle
Y(4008)
Y(4260)
Events / 20 MeV
M(J/ψ π⁺π⁻) / GeV
Belle
Y(4350)
Y(4660)
Events / 25 MeV
M(ψ′ π⁺π⁻) / GeV
BaBar
Y(4260)
Events / 20 MeV
M(J/ψ π⁺π⁻) / GeV
BaBar
Y(4350)
Y(4660)
Events / 50 MeV
M(ψ′ π⁺π⁻) / GeV

OVERPOPULATION OF $J^{PC}=1^{--}$ STATES





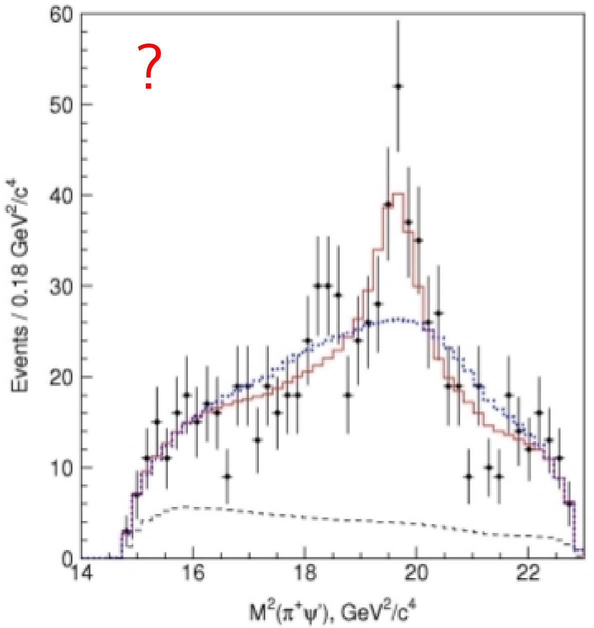
- Non-trivial two-doublet pattern
- No higher states up to 7.0 GeV
- Dominated by $J/\psi f_0(980)$ (I=0)

  $\rightarrow$ no indication for isospin violation
  but decays to Z(3900) isospin triplet
- decay to e^+e^- not seen (although 1– –)
  decay to D(*)D(*) not seen (although phasespace huge)
  $\rightarrow$ „hybrid" ?

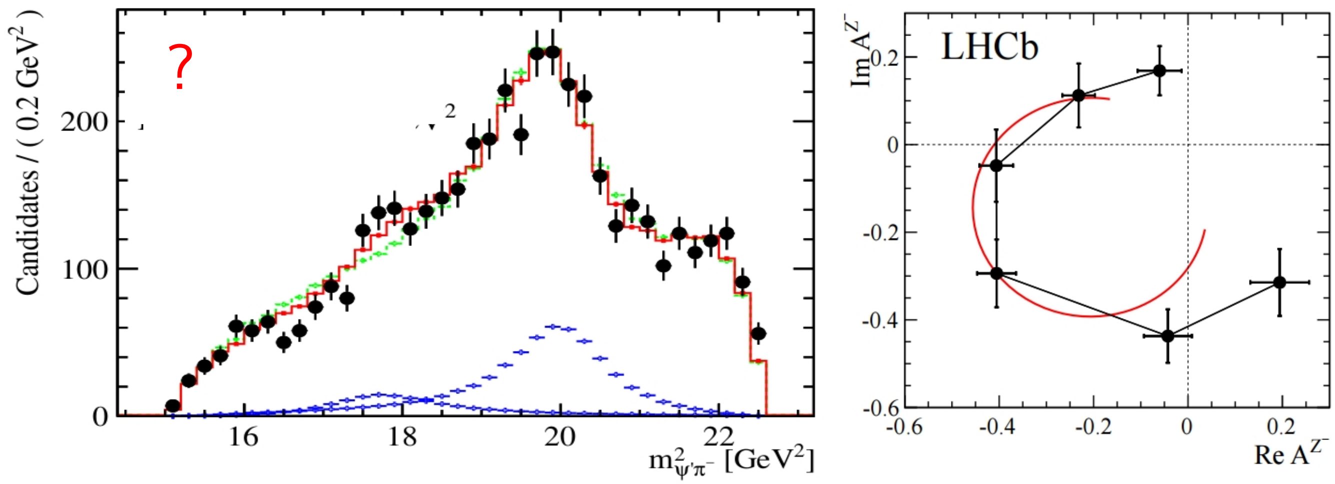
e+e– machines only (ISR)

?

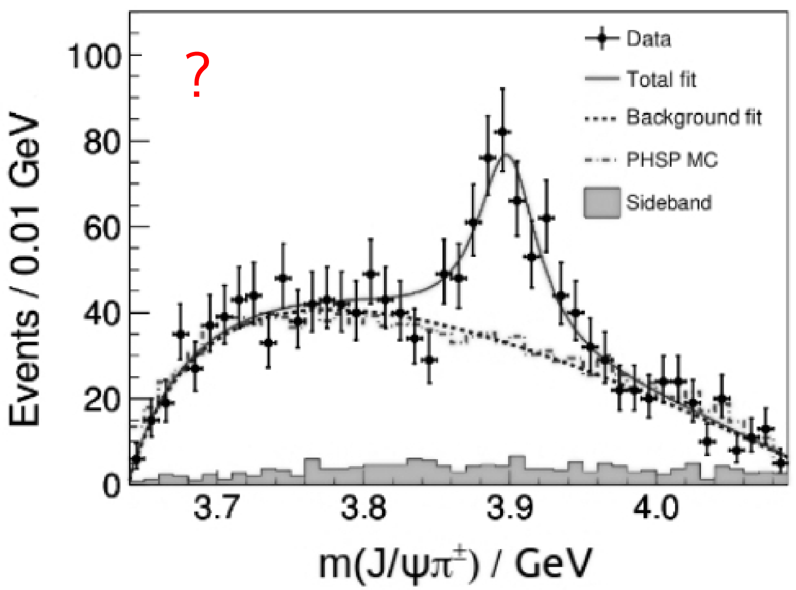
Belle, Phys. Rev D80(2009)031104



LHCb, Phys. Rev. Lett. 112(2014)222002



BESIII, Phys. Rev. Lett. 110(2013)252001

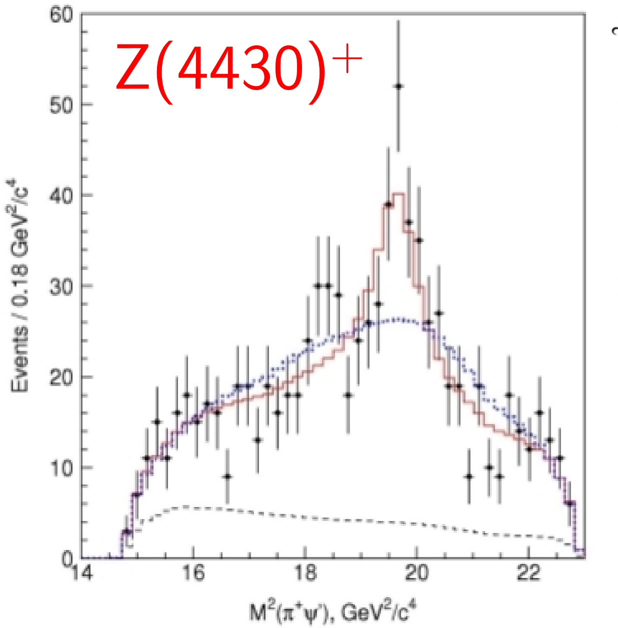


$$B^0 \to K^\pm \underbrace{\psi'\pi^\mp}_{\text{resonant state?}}$$

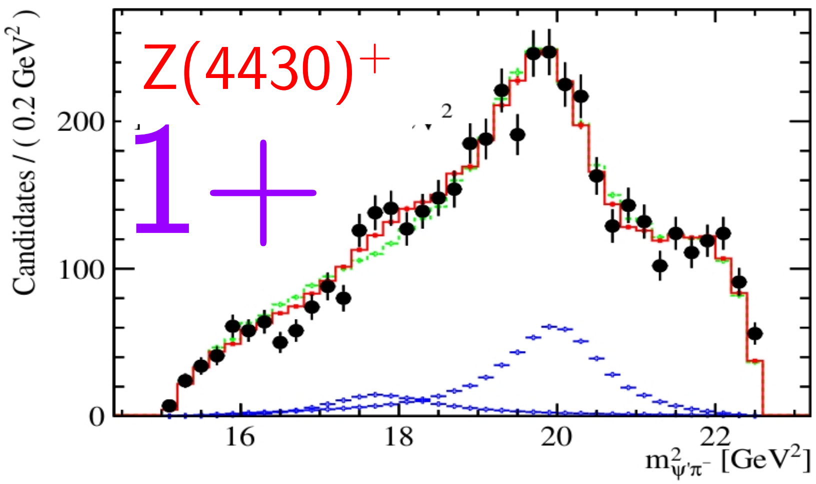
$$e^+e^- \to (\ Y(4260)\ ) \to \underbrace{J/\psi\pi^\pm}_{\text{resonant state?}} \ \pi^\mp$$

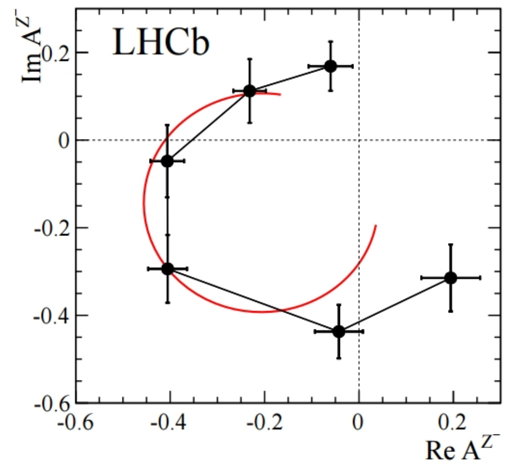
Z STATES

Belle, Phys. Rev D80(2009)031104

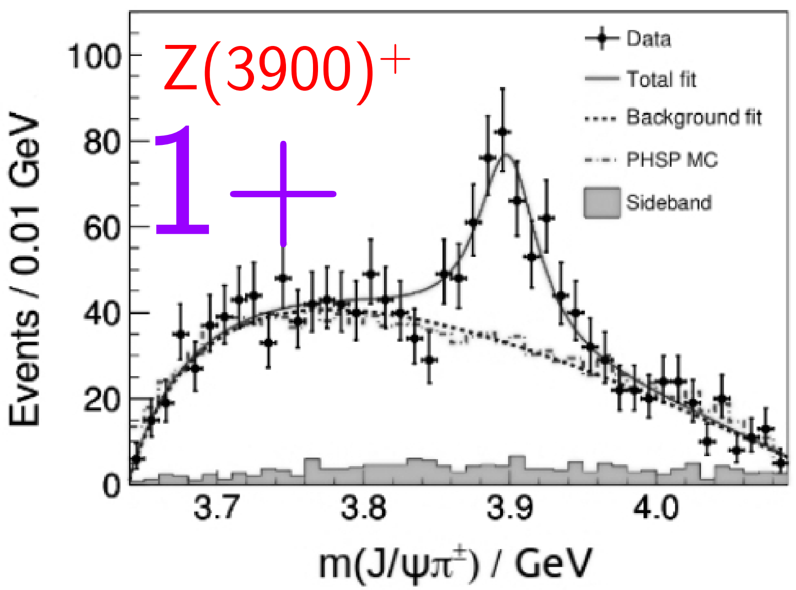


LHCb, Phys. Rev. Lett. 112(2014)222002





BESIII, Phys. Rev. Lett. 110(2013)252001

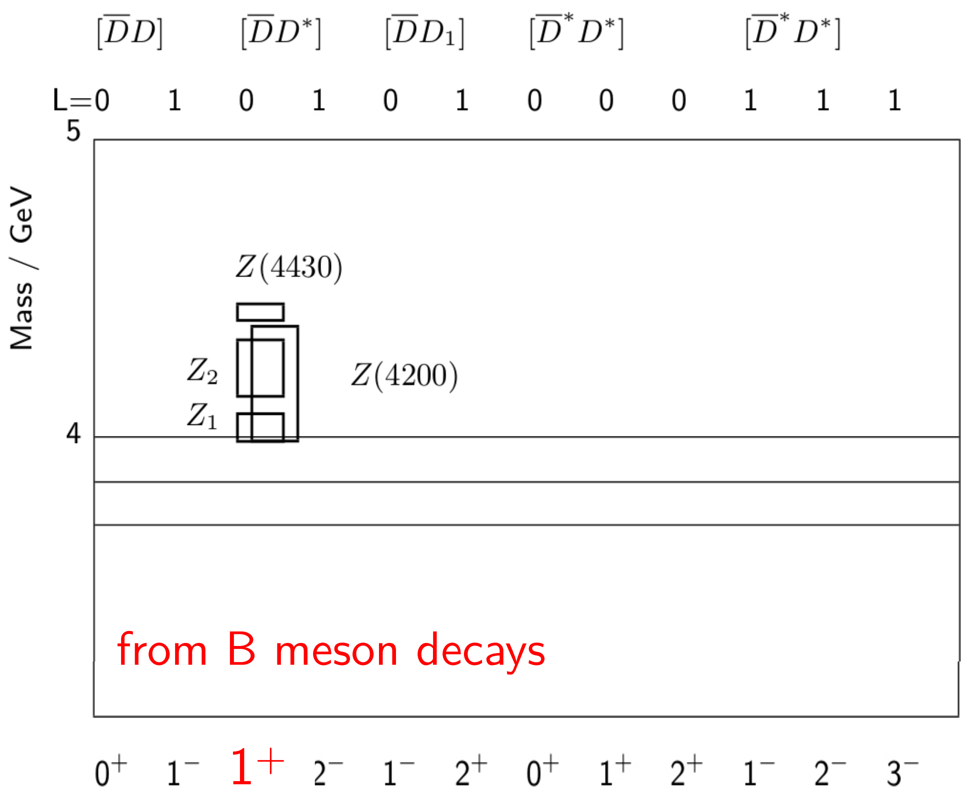


CHARGED

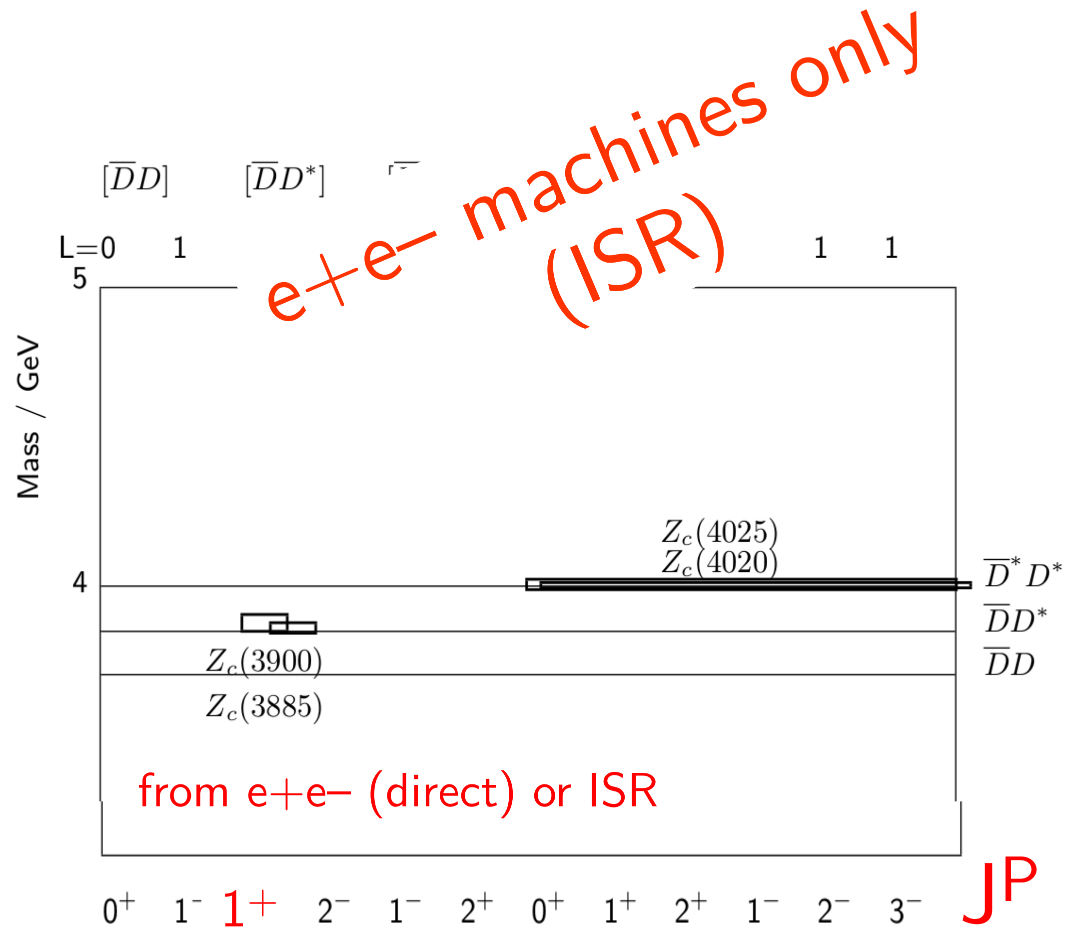
$$B^0 \to K^\pm \underbrace{\psi' \pi^\mp}_{\text{resonant state?}}$$

$$e^+e^- \to (\ Y(4260)\ ) \to \underbrace{J/\psi \pi^\pm}_{\text{resonant state?}} \pi^\mp$$

TWO DIFFERENT CLASSES OF Z STATES ?



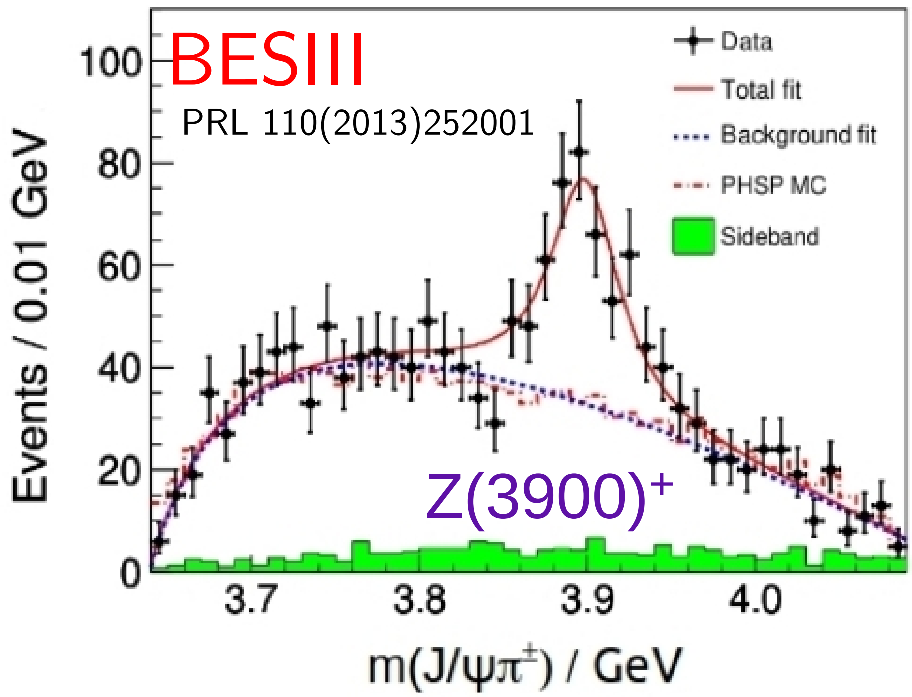
- large widths
- not connected to thresholds?

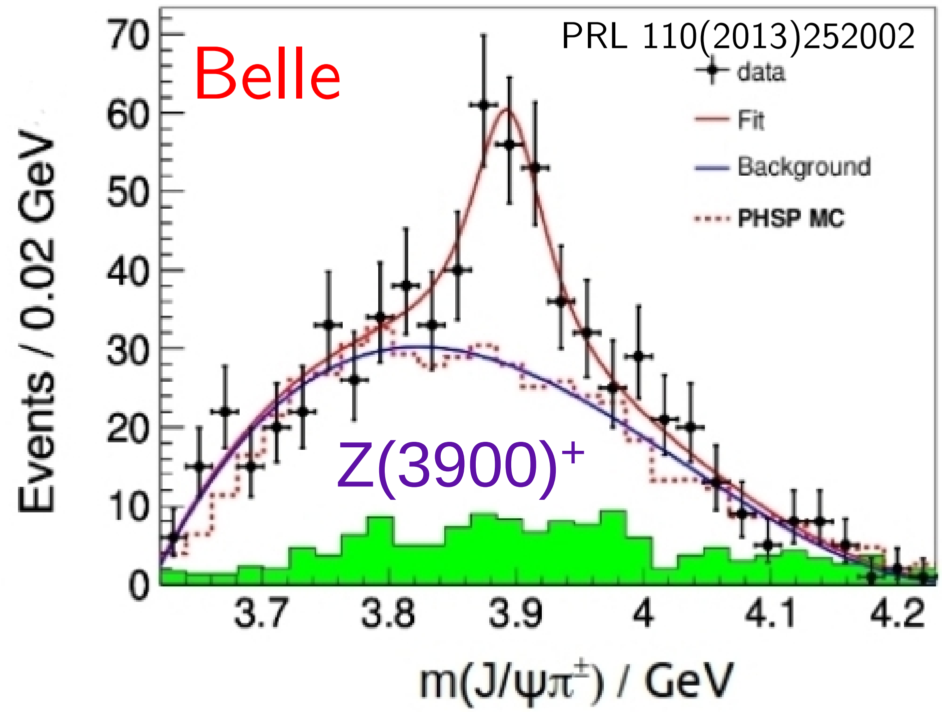


- narrow widths
- near thresholds

Only Belle II can do both.

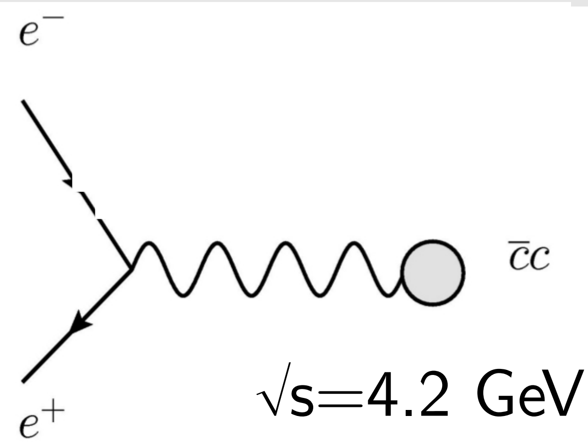
$$e^+e^- \to (\ Y(4260)\ ) \to \quad J/\psi\pi^\pm \quad \pi^\mp$$



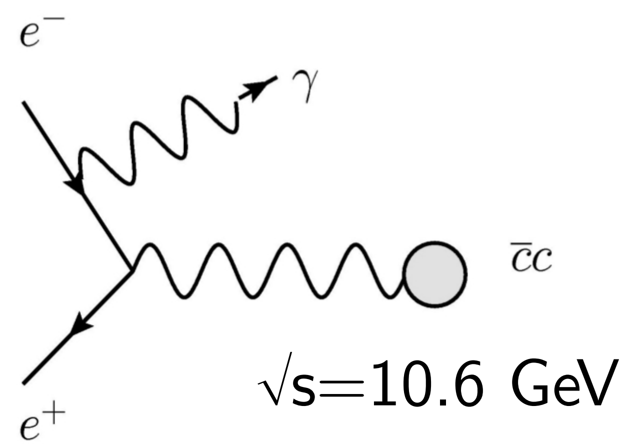


Data taking ≃4 weeks

Data taking ≃10 years



Direct Production

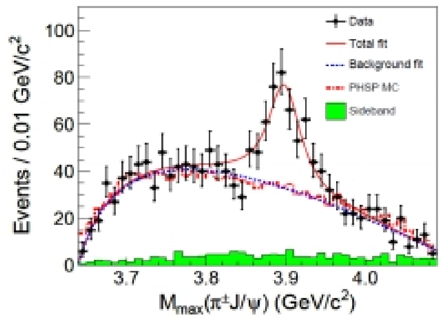


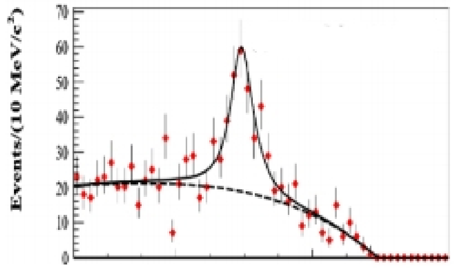
Initial State Radiation (ISR)

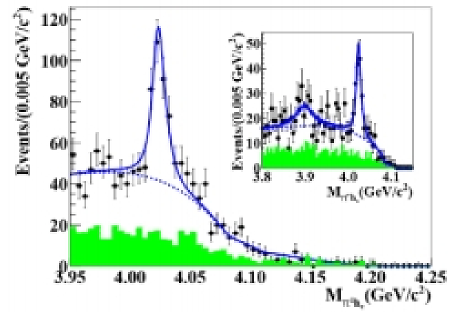
Landiao LIU, QWG 2016

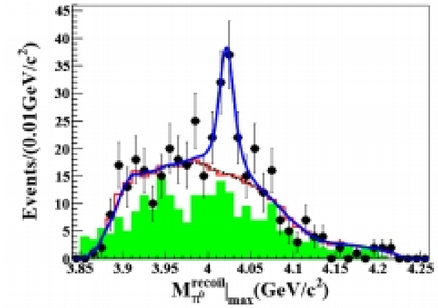
Z STATES AT BESIII

$D\bar{D}^*$ threshold | $D^*\bar{D}^*$ threshold

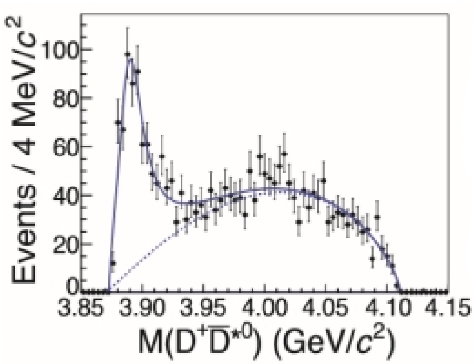


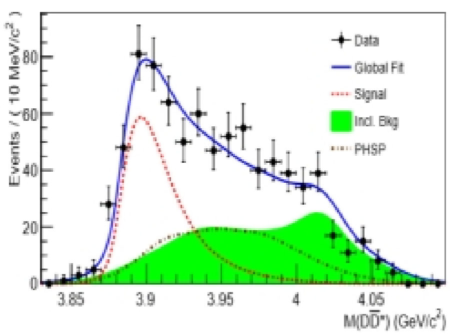


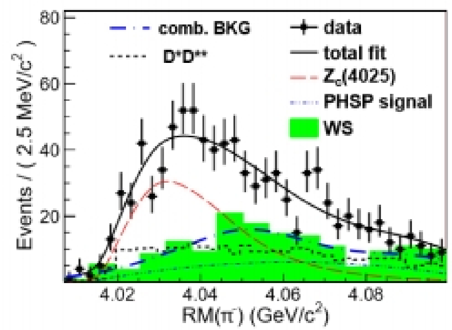


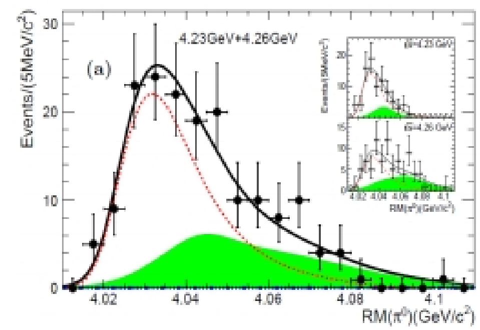


$e^+e^- \to \pi^+ \pi^- J/\Psi$ | $e^+e^- \to \pi^0 \pi^0 J/\Psi$ | $e^+e^- \to \pi^+ \pi^- h_c$ | $e^+e^- \to \pi^0 \pi^0 h_c$









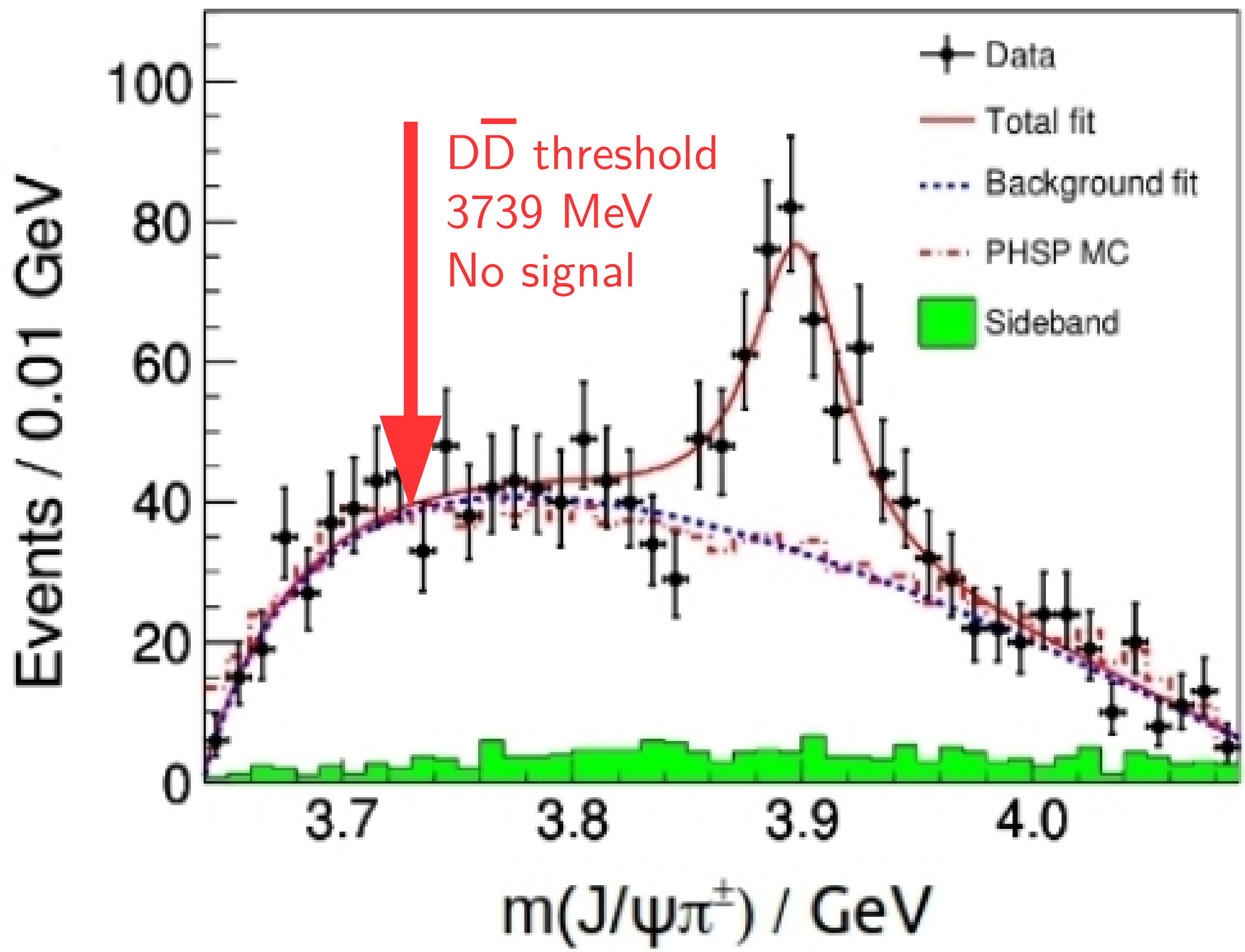
$e^+e^- \to \pi^+ (D\bar{D}^*)^-$ | $e^+e^- \to \pi^0 (D\bar{D}^*)^0$ | $e^+e^- \to \pi^+ (D^*\bar{D}^*)^-$ | $e^+e^- \to \pi^0 (D^*\bar{D}^*)^0$

charged | neutral | charged | neutral

All of them 1+, whereever tested.

What about the $D\bar{D}$ threshold?

Z AT $D\bar{D}$ THRESHOLD ?



„Wrong“ J^P: $D\bar{D}$ gives 0+, $J/\psi\pi$ gives 1+ in S-wave, 0– in P-wave

Would be accessible in $h_c\pi$, but phasespace very small

PUZZLE: all measured Z^+ masses are <u>above</u> thresholds

State	m/MeV	Threshold	$\Delta m/\mathrm{MeV}$
$Z_c(3900)$	$3899.0\pm3.6\pm4.9$	$D^+\overline{D}^{0*}$	$+22.4$
$Z_c(3900)$	$3899.0\pm3.6\pm4.9$	$D^0\overline{D}^{+*}$	$+23.9$
$Z_c(3900)$	$3894.5\pm6.6\pm4.5$	$D^+\overline{D}^{0*}$	$+17.9$
$Z_c(3900)$	$3894.5\pm6.6\pm4.5$	$D^0\overline{D}^{+*}$	$+19.4$
$Z_c(3900)$	$3885\pm5\pm1$	$D^+\overline{D}^{0*}$	$+8.4$
$Z_c(3900)$	$3885\pm5\pm1$ MeV	$D^0\overline{D}^{+*}$	$+9.9$
$Z_c(3885)$	$3883.9\pm1.5\pm4.2$	$D^+\overline{D}^{0*}$	$+7.4$
$Z_c(3885)$	$3883.9\pm1.5\pm4.2$	$D^0\overline{D}^{+*}$	$+8.8$
$Z_c(4020)$	$4022.9\pm0.8\pm2.7$	$D^{0*}\overline{D}^{\pm*}$	$+5.6$
$Z_c(4025)$	$4026.3\pm2.6\pm3.7$	$D^{0*}\overline{D}^{\pm*}$	$+9.0$

	possible?
threshold effect	yes (by loops)
tetraquark	yes (spin–spin forces)
molecules	no, if bound state (pole below threshold, $E_B>0$)

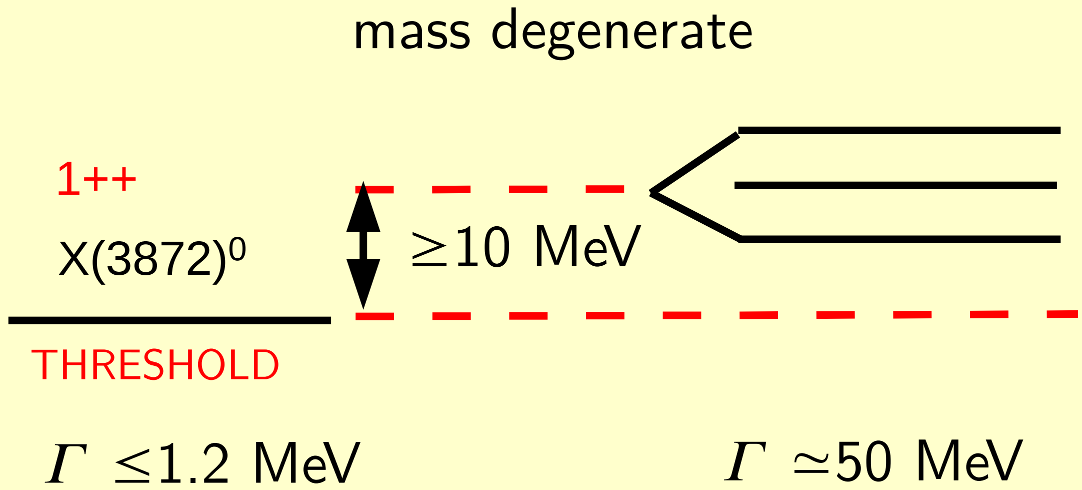
CHARGED AND NEUTRAL Z

State	m [MeV]	Width [MeV]	Decay
$Z_c(3900)^+$	$3899.0 \pm 3.6 \pm 4.9$	$46 \pm 10 \pm 20$	$J/\psi\pi^+$
$Z_c(3900)^0$	$3894.8 \pm 2.3 \pm 2.7$	$29.6 \pm 8.2 \pm 8.2$	$J/\psi\pi^0$
$Z_c(3885)^+$	$3883.9 \pm 1.5 \pm 4.2$	$24.8 \pm 3.3 \pm 1.0$	$(DD^*)^+$
$Z_c(3885)^0$	$3885.7^{+4.3}_{-5.7} \pm 8.4$	$35^{+11}_{-12} \pm 15$	$(DD^*)^0$
$Z_c(4020)^+$	$4022.9 \pm 0.8 \pm 2.7$	$7.9 \pm 2.7 \pm 2.6$	$h_c\pi^+$
$Z_c(4020)^0$	$4023.8 \pm 2.2 \pm 3.8$	Fixed to 7.9	$h_c\pi^0$
$Z_c(4025)^+$	$4026.3 \pm 2.6 \pm 3.7$	$24.8 \pm 5.6 \pm 7.7$	$(D^*D^*)^+$
$Z_c(4025)^0$	$4025.5^{+2.0}_{-4.7} \pm 3.1$	$23.0 \pm 6.0 \pm 1.0$	$(D^*D^*)^0$

4-quark content:
charged Z $[c\bar{c}u\bar{d}]$, neutral Z $[c\bar{c}u\bar{u}]$,$[c\bar{c}d\bar{d}]$
$\rightarrow$ masses may be different

BESIII, Phys. Rev. Lett. 110 (2013) 252001
BESIII, Phys. Rev. Lett. 115 (2015) 112003
BESIII, Phys. Rev. Lett. 112 (2014) 022001
BESIII, Phys. Rev. Lett. 115 (2015) 222002
BESIII, Phys. Rev. Lett. 111 (2013) 242001
BESIII, Phys. Rev. Lett. 113 (2014) 212002
BESIII, Phys. Rev. Lett. 112 (2014) 13200
BESIII, Phys. Rev. Lett. 115 (2015) 182002

X(3872) AND Z(3900) ISOSPIN TRIPLET



for parity assume L=0
(close to threshold)

Z(3900)$^+$	1+
Z(3900)^0	1+ −
Z(3900)$^-$	1+

Is the Z(3900)$^{+,0,-}$ the isospin partner to the X(3872)?
No!
Wrong G-parity.

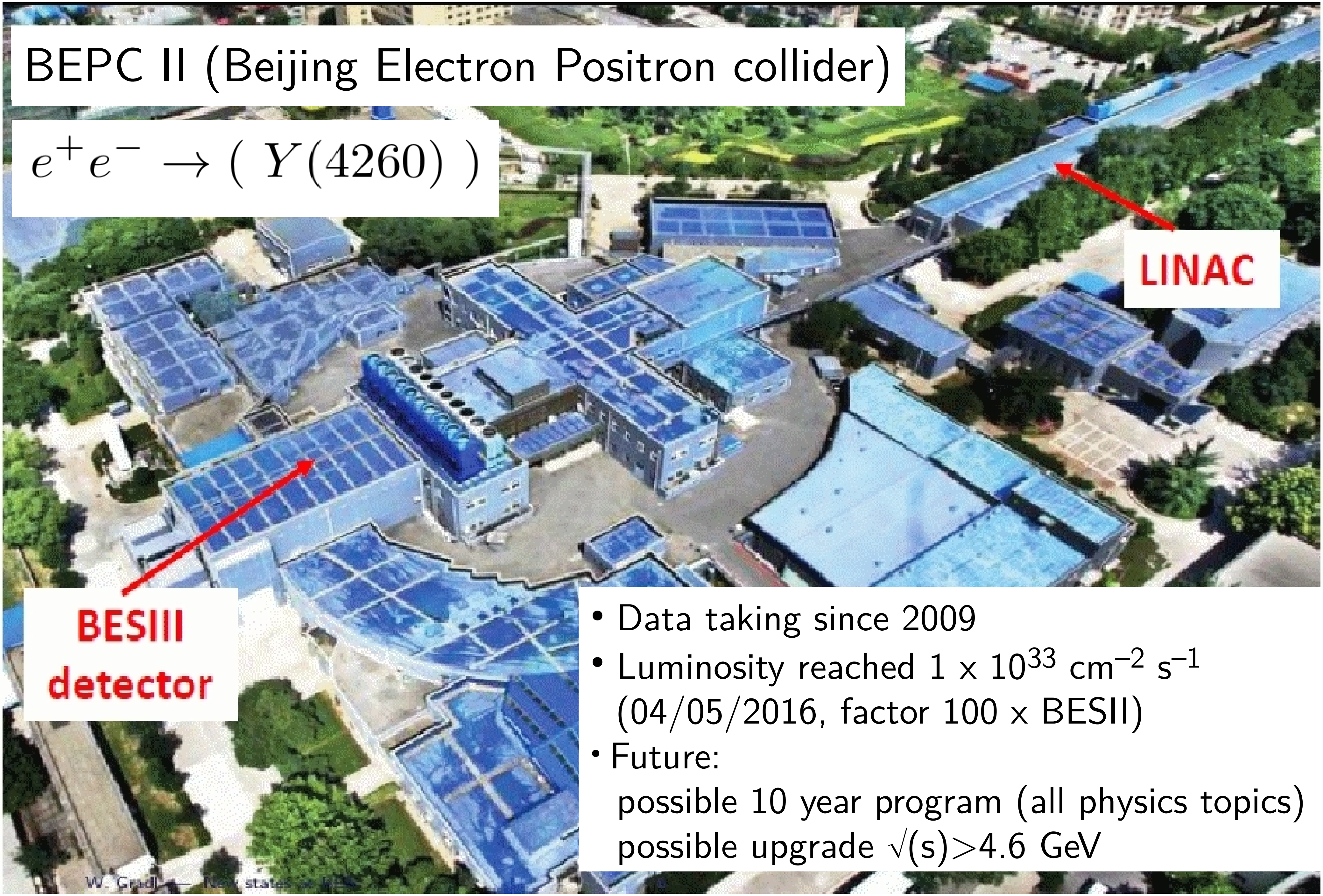
HIGH LUMINOSITY EXPERIMENTS

LHCb $\rightarrow$ see talks by
S. Eidelman
T. Skwarnicki

BESIII

BEPC II (Beijing Electron Positron collider)

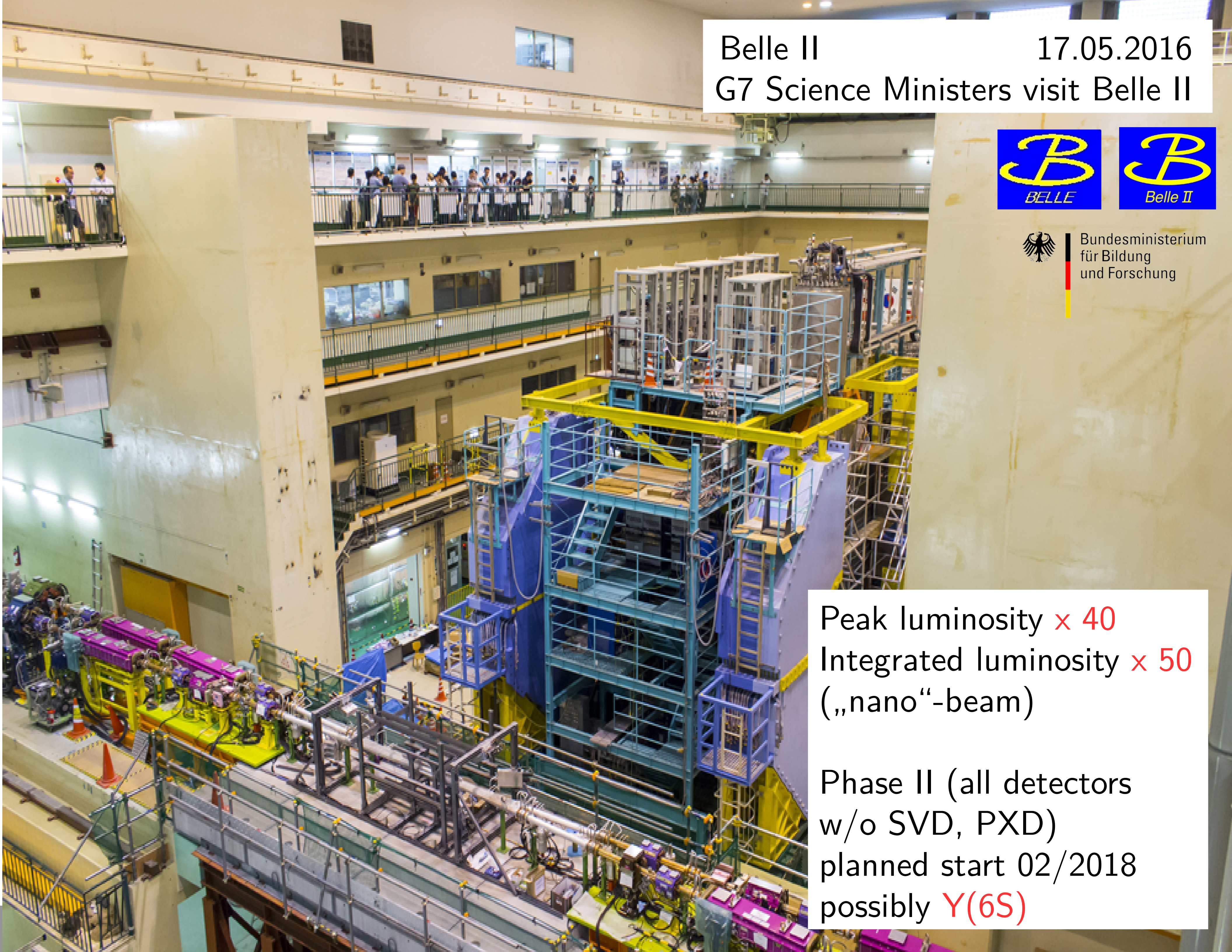
$$e^+e^- \rightarrow (\ Y(4260)\ )$$



- Data taking since 2009
- Luminosity reached 1 x 10^{33} cm^{-2} s^{-1} (04/05/2016, factor 100 x BESII)
- Future:
  possible 10 year program (all physics topics)
  possible upgrade √(s)>4.6 GeV

Belle II 17.05.2016

G7 Science Ministers visit Belle II



Bundesministerium für Bildung und Forschung

Peak luminosity x 40
Integrated luminosity x 50
(„nano“-beam)

Phase II (all detectors w/o SVD, PXD)
planned start 02/2018
possibly Y(6S)

$\overline{\text{P}}$ANDA

HESR ($\overline{\text{P}}$ANDA storage ring)
dipole magnets in Jülich
first delivery to Darmstadt

Potential run plan:
startup phase
1×10^{31} cm^{-2} s^{-1}

J. Ritman, COMPASS beyond 2020 workshop, CERN, 03/2016

NUMBER OF XYZ PER DAY

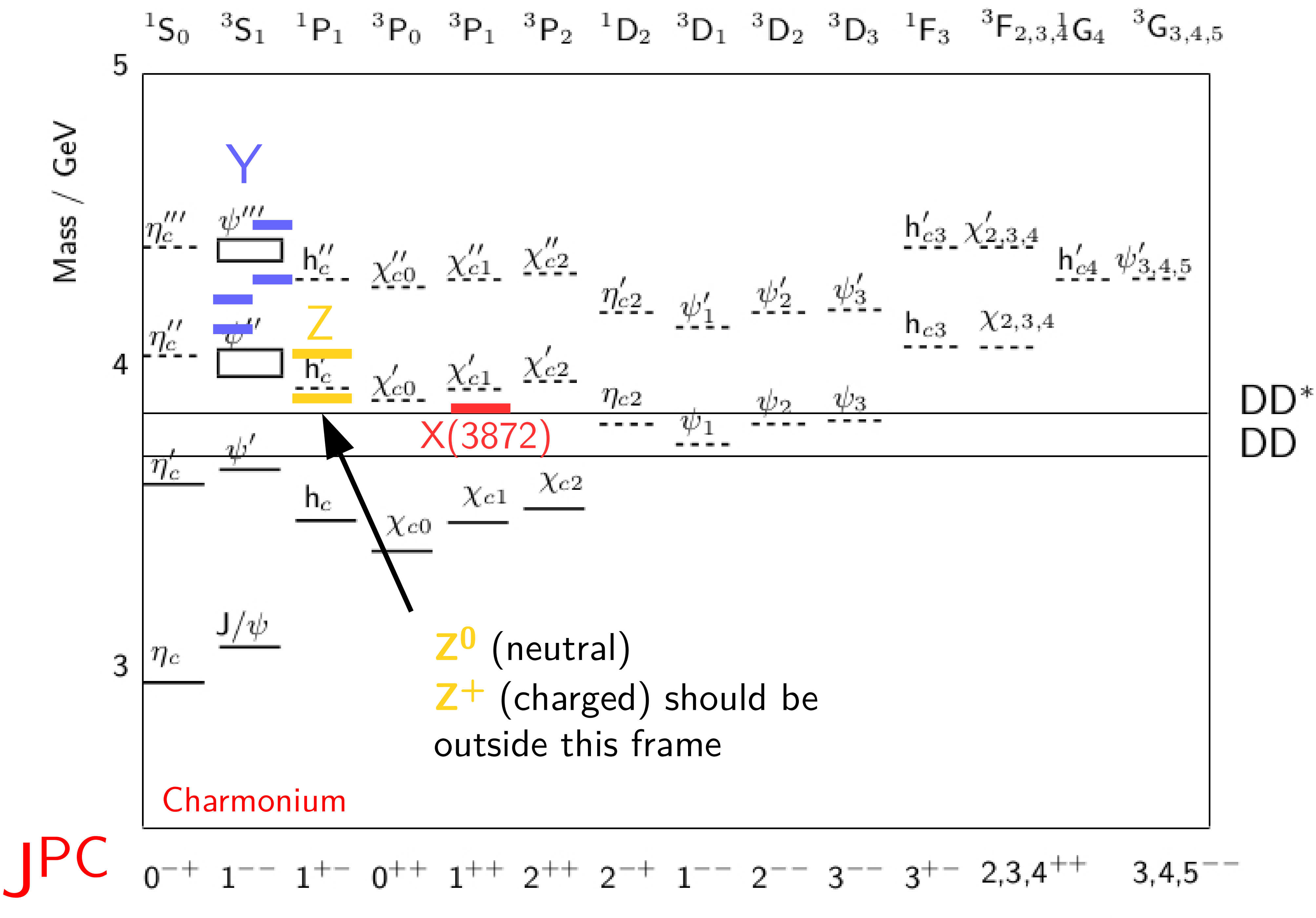
	BESIII	BELLE II (scaled from Belle, assume 40 fb^{-1} per day)
X(3872	0.7 (radiative)	8.5 (Belle was 0.2)
Y(4260)	50	23.6
Z(3900)	10	5.0
Z(4430)	–	8.3
	LHCb (assume 2 fb–1/year)	$\overline{\text{P}}$ANDA 1311.7597[hep-ex] (startup, $\mathcal{L}$=1 x 10^{31} cm^{-2} s^{-1})
X(3872)	1.7 (trigger)	65 (50 nb, $\mathcal{B}$=5%)
Y(4260)	–	1900 (<67) (2 nb, $\mathcal{B}$=100%)
Z(3900)	–	405 (<14)
Z(4430)	4.7	–

Numbers are private estimates, by scaling from publications.
Events reconstructed in $J/\psi\pi(\pi)$.
Luminosity per day fixed (i.e. luminosity profiles not taken into account)

WHAT ADDITIONAL STATES ARE REQUIRED ?

WHICH ONE IS THE HOLY GRAIL ?

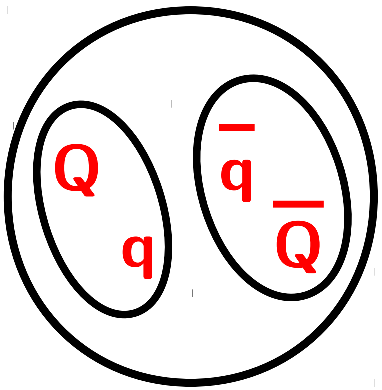
PLEASE
KEEP IN MIND
THE FOLLOWING
PATTERN



Barnes, Godfrey, Swanson, Phys. Rev. D72(2005)054026

READY ?

TETRAQUARK
DIQUARK ANTI–DIQUARK MODEL

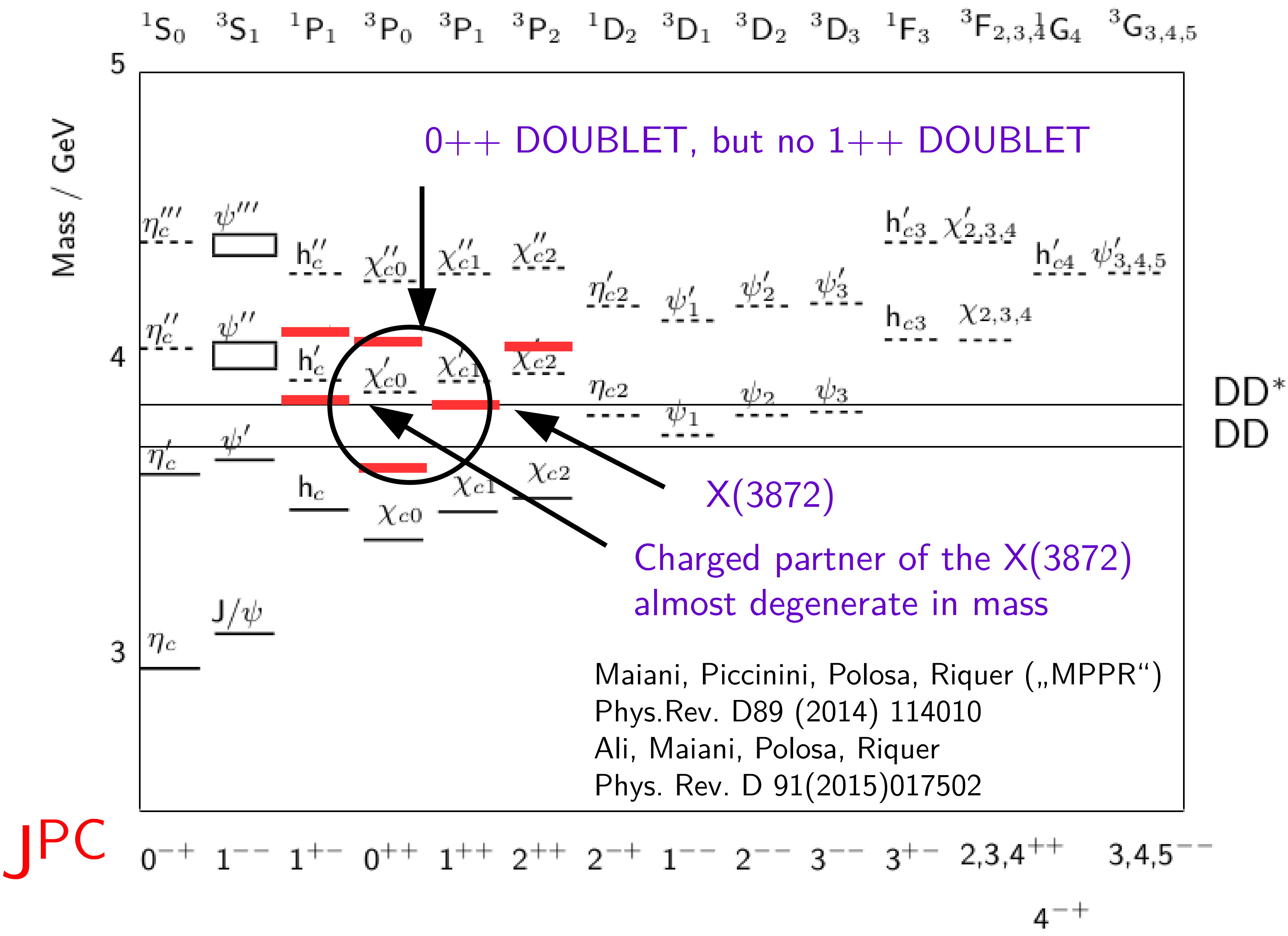


$[qQ]_8[\overline{qQ}]_8$

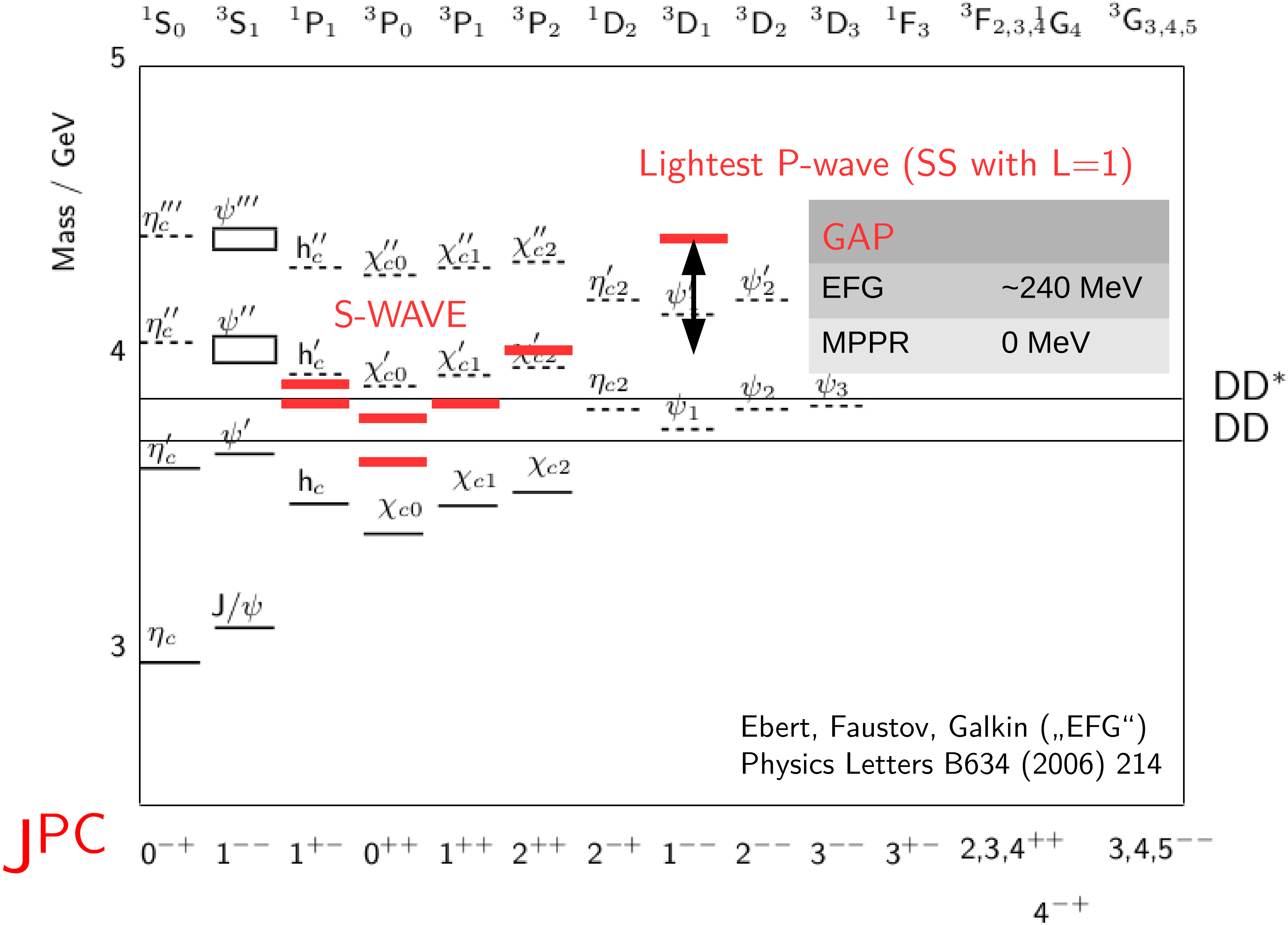
diquarks
are colored

State J^{PC}		Diquark content
$1S$		
0^{++}		$S\bar{S}$
$1^{+\pm}$		$(S\bar{A} \pm \bar{S}A)/\sqrt{2}$
0^{++}	S scalar	$A\bar{A}$
1^{+-}	A axial–vector	$A\bar{A}$
2^{++}		$A\bar{A}$
$1P$		
1^{--}		$S\bar{S}$

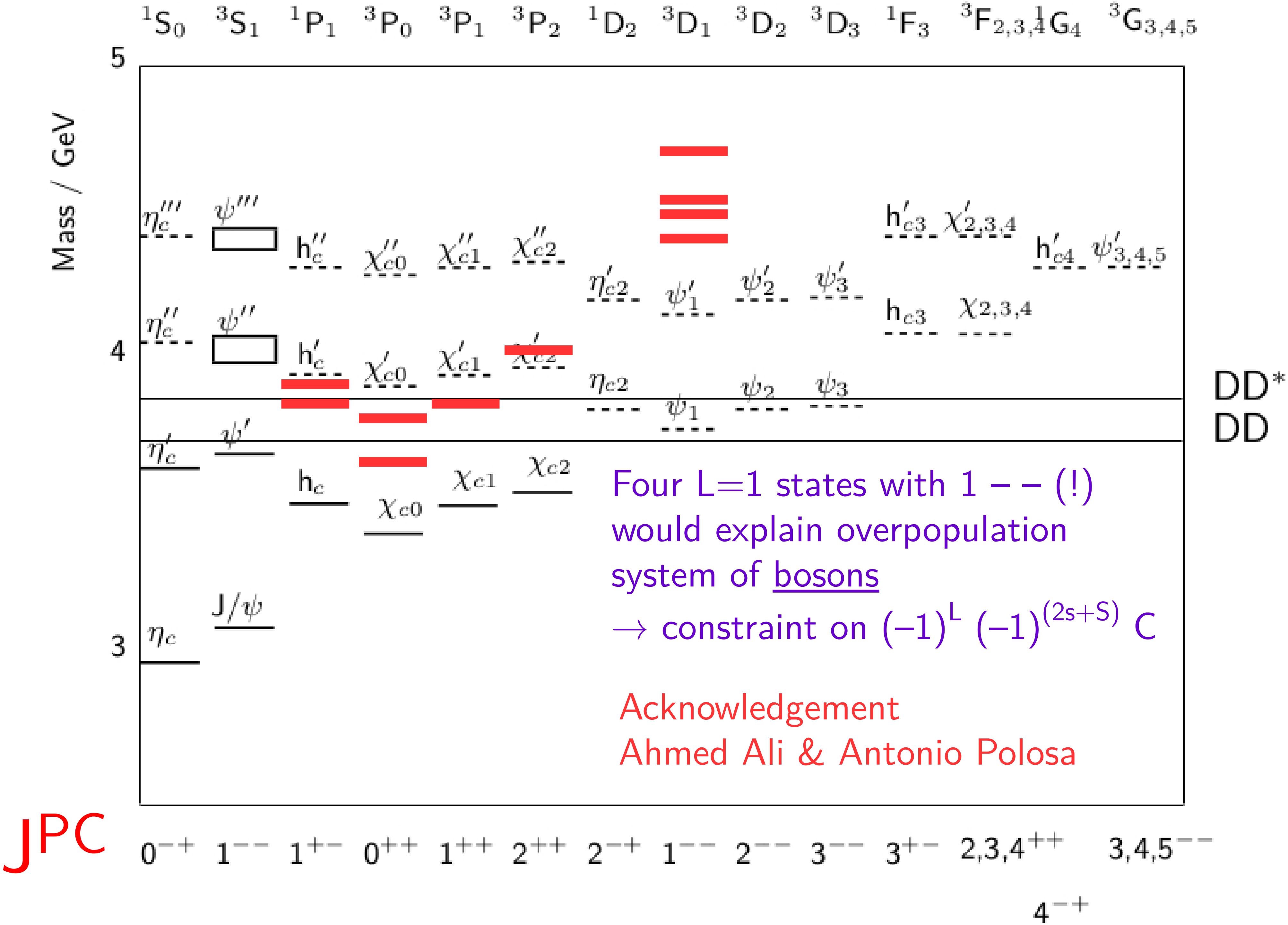
Ebert, Faustov, Galkin
Physics Letters B 634 (2006) 214–219



0++ DOUBLET, but no 1++ DOUBLET
X(3872)
Charged partner of the X(3872)
almost degenerate in mass
Maiani, Piccinini, Polosa, Riquer („MPPR“)
Phys.Rev. D89 (2014) 114010
Ali, Maiani, Polosa, Riquer
Phys. Rev. D 91(2015)017502
Mass / GeV
DD*
DD
JPC



Lightest P-wave (SS with L=1)
GAP
EFG ~240 MeV
MPPR 0 MeV
S-WAVE
Mass / GeV
DD*
DD
Ebert, Faustov, Galkin („EFG“)
Physics Letters B634 (2006) 214
JPC

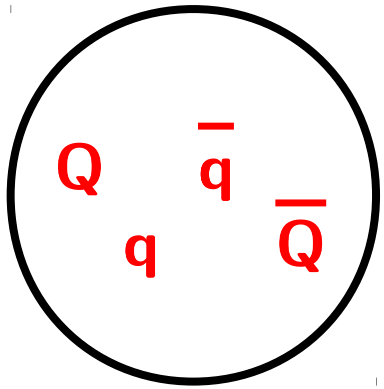


Four L=1 states with 1 – – (!)
would explain overpopulation
system of bosons

$\rightarrow$ constraint on $(-1)^L\ (-1)^{(2s+S)}\ C$

Acknowledgement
Ahmed Ali & Antonio Polosa

4–QUARK MODEL



$$H = \sum_i m_i + H_{\rm CM},$$

$$H_{\rm CM} = -\sum_{i,j} C_{ij}\,\lambda_i^c \cdot \lambda_j^c\,\vec{\sigma}_i \cdot \vec{\sigma}_j.$$

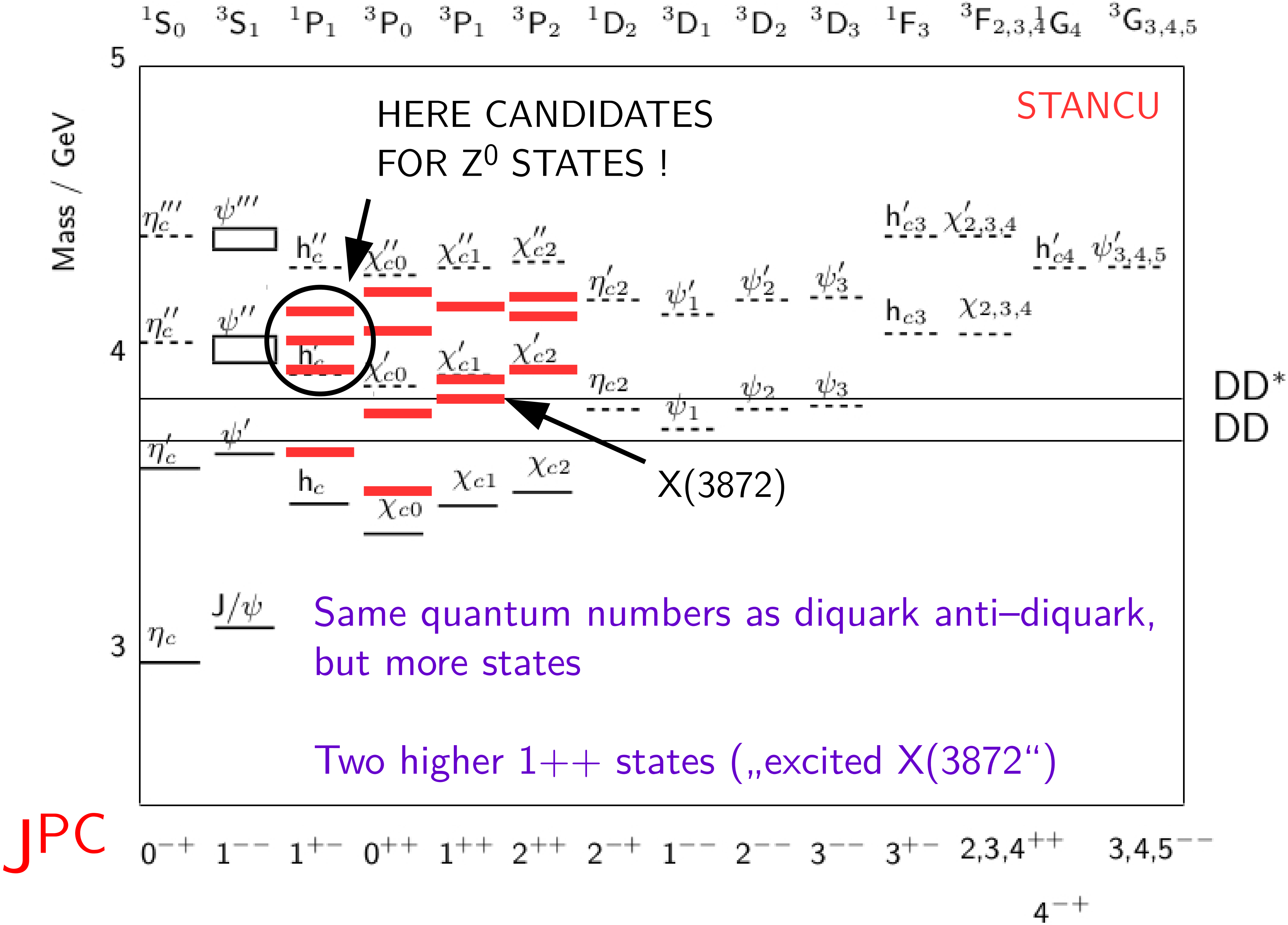
$C_{cs} = 5.0$ MeV, $C_{c\bar{c}} = 5.5$ MeV,

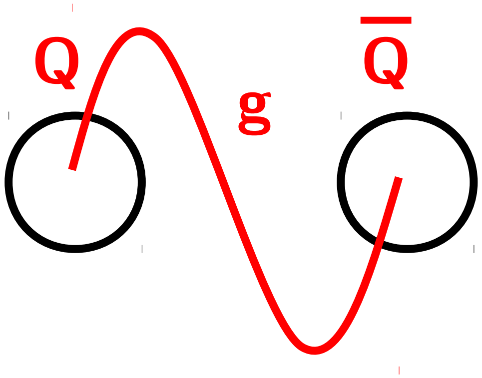
$C_{c\bar{s}} = 6.7$ MeV, $C_{s\bar{s}} = 8.6$ MeV.

4 quarks
(not diquark anti–diquark)

Color-spin basis
(singlet-singlet, octet-octet)

F. Stancu
Phys. Rev. D 57(1998)6778
F. Stancu, D. Brink
arXiv:hep-ph/0607077


HERE CANDIDATES
FOR Z0 STATES !
STANCU
X(3872)
DD*
DD
Mass / GeV
Same quantum numbers as diquark anti–diquark,
but more states
Two higher 1++ states („excited X(3872“)
JPC



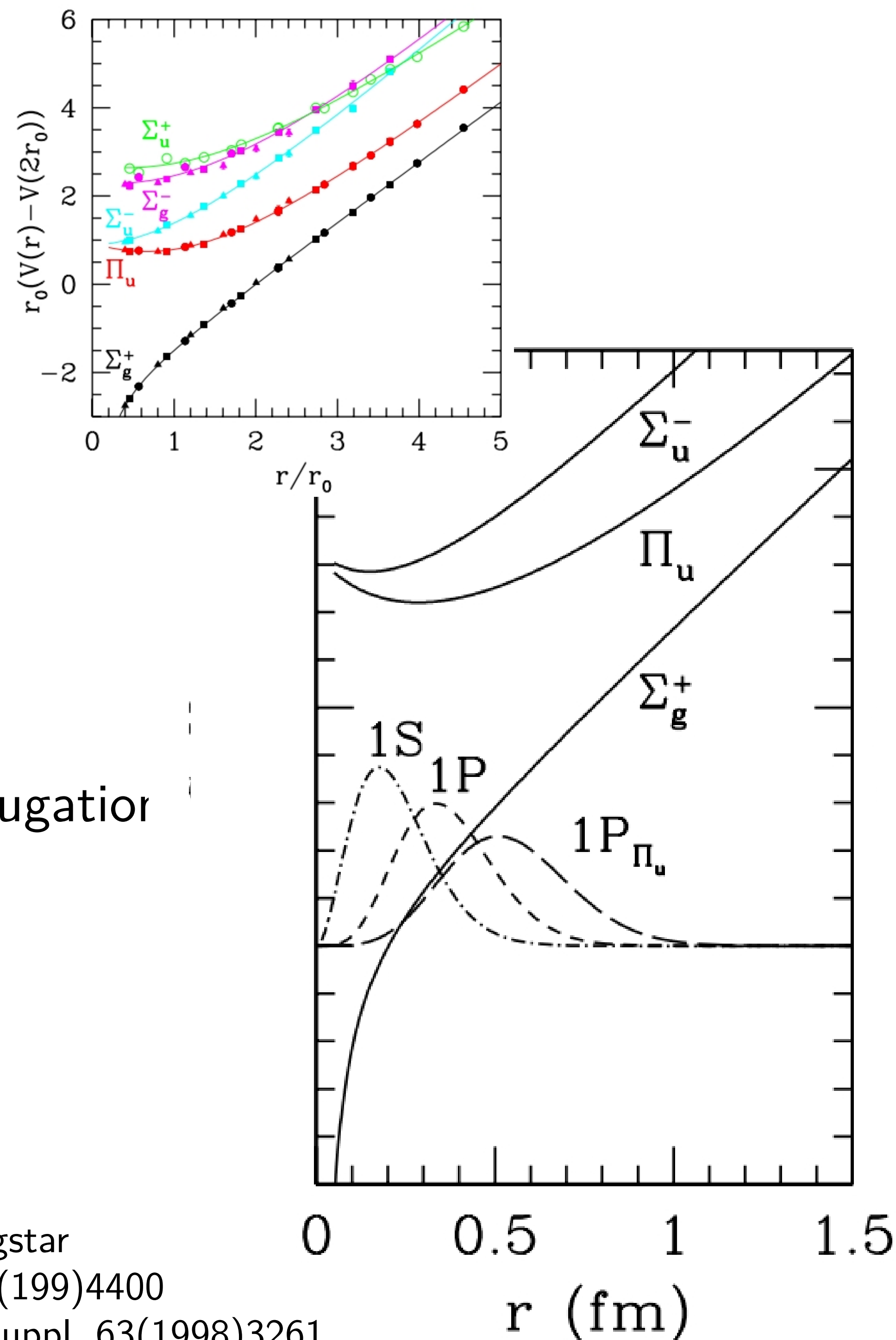
$[Q\bar{Q}]_8 g$

HYBRID POTENTIALS

projection of gluon angular momentum onto QQ axis
0,1,2,... $\rightarrow$ Σ, Π, Δ, ...

product of gluonic parity and charge conjugation $(PC)_g$
„u“ (negative), „d“ (positive)

reflection of system through plane containing QQ axis
Superscript „+“ or „–„



Juge, Kuti, Morningstar
Phys. Rev. Lett. 82(199)4400
Nucl. Phys. Proc. Suppl. 63(1998)3261

	S	L	J^{PC}
η_c	0	0	0^{-+}
J/ψ	1	0	1^{--}
h_c	0	1	1^{+-}
χ_c	1	1	$(0, 1, 2)^{++}$

CORNELL POTENTIAL

Table 3: Σ_g^+ Meson Quantum Numbers.

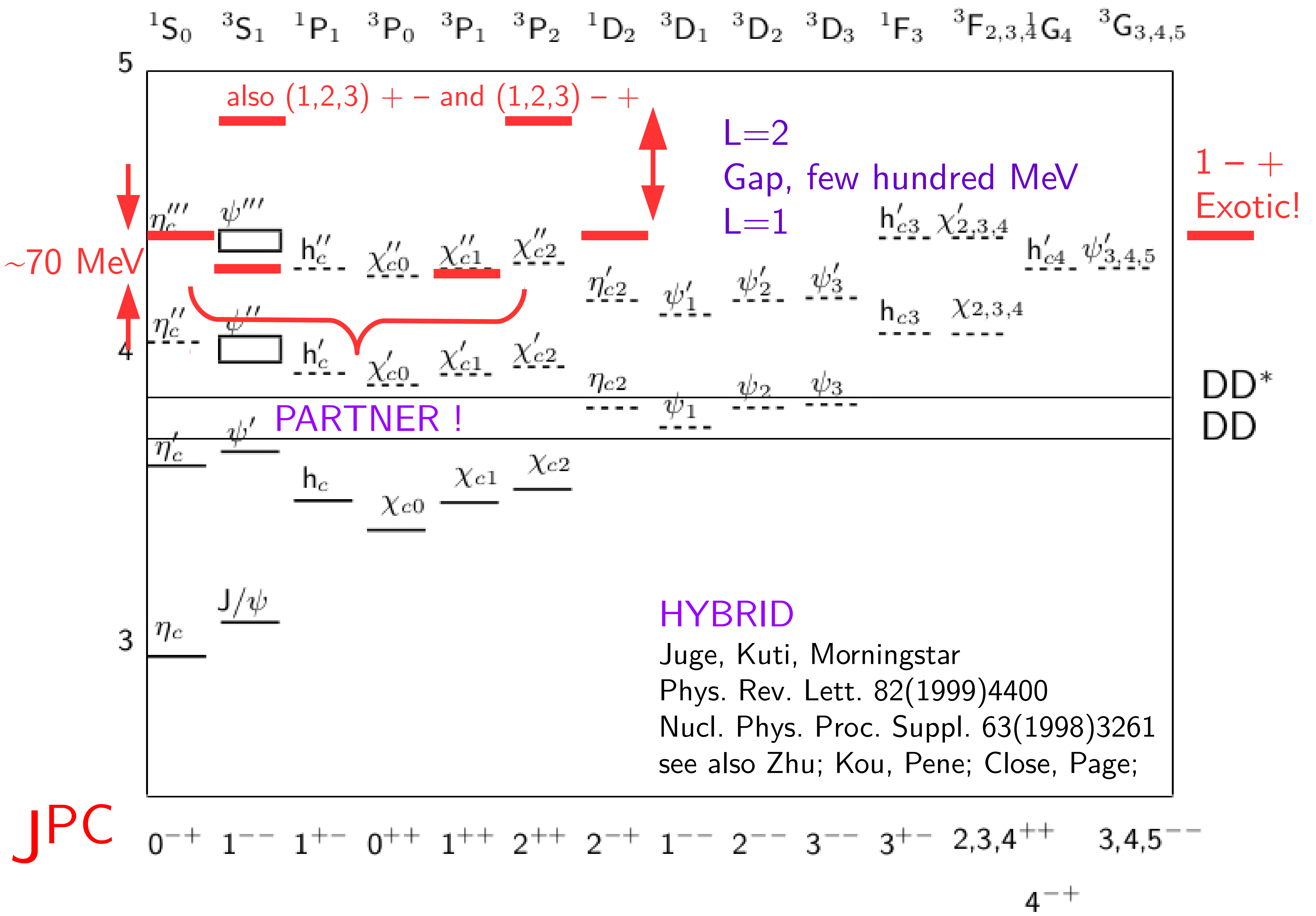
MASS

S	L	J^{PC}
0	1	1^{--}, 1^{++}
1	1	$(0, 1, 2)^{-+}$, $(0, 1, 2)^{+-}$
0	2	2^{++}, $2--$
1	2	$(1, 2, 3)^{+-}$, $(1, 2, 3)^{-+}$

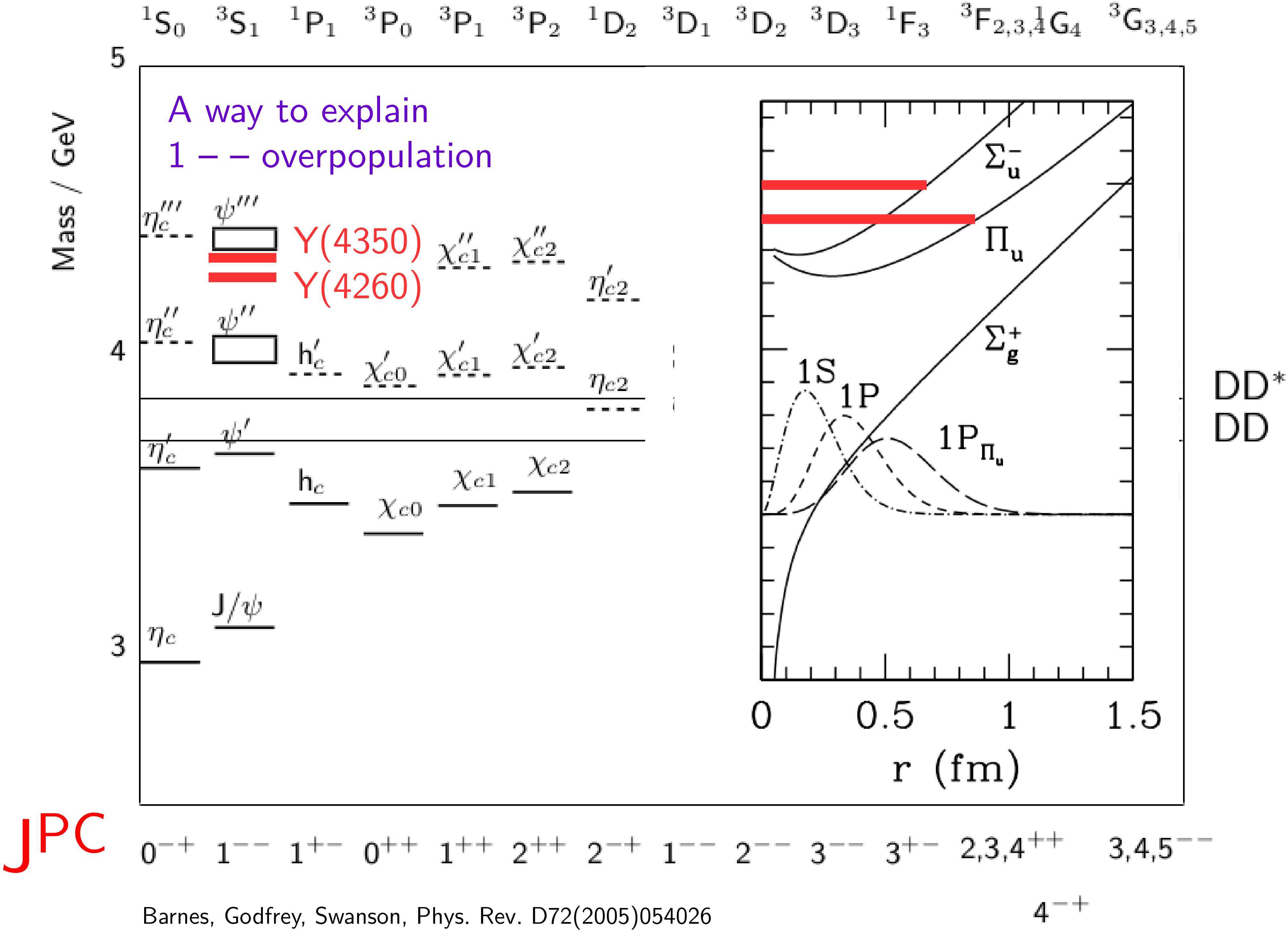
A GLUONIC POTENTIAL: HERE Π_u

Table 4: Π_u Meson Quantum Numbers.

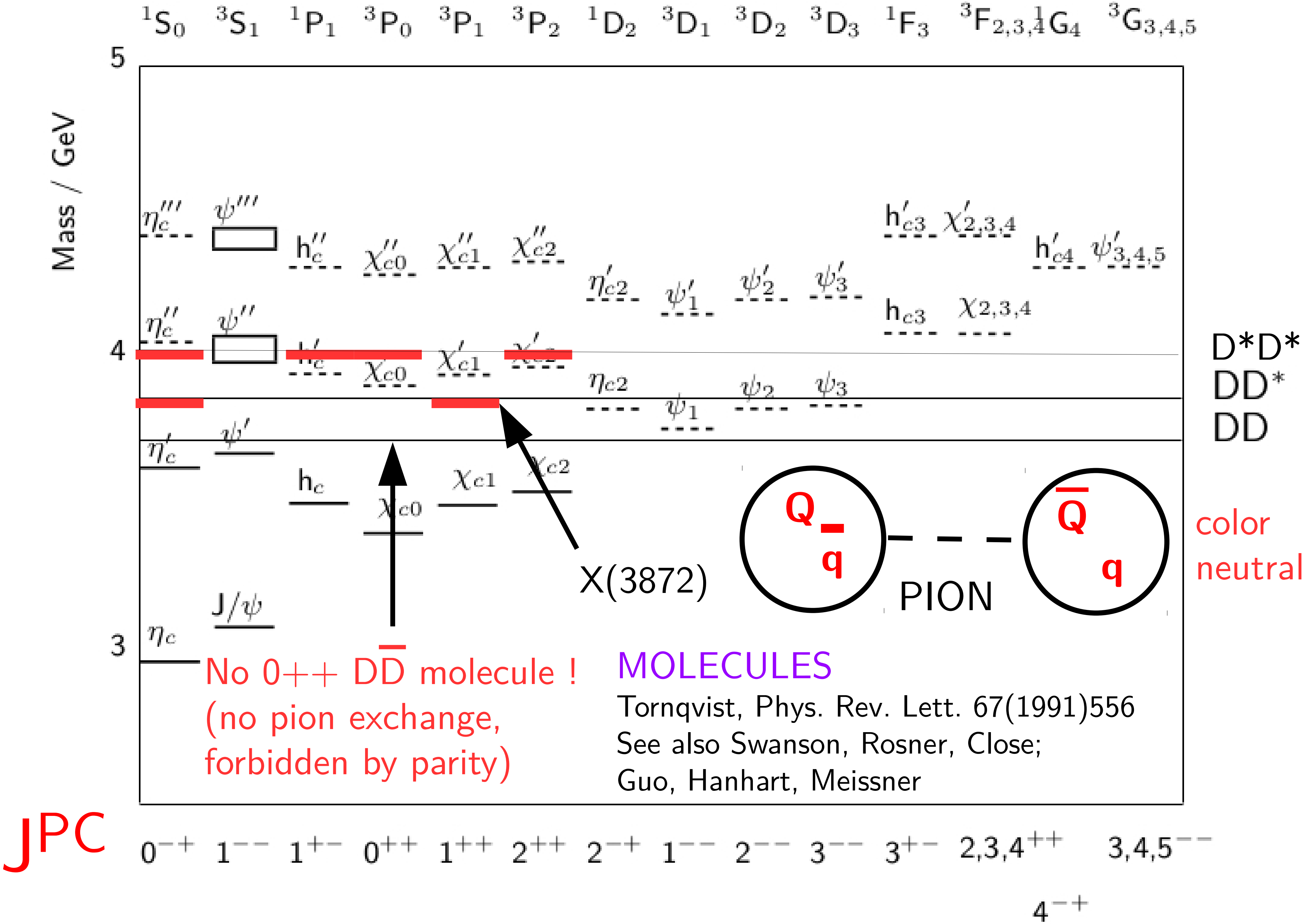
Mass lower   Mass higher

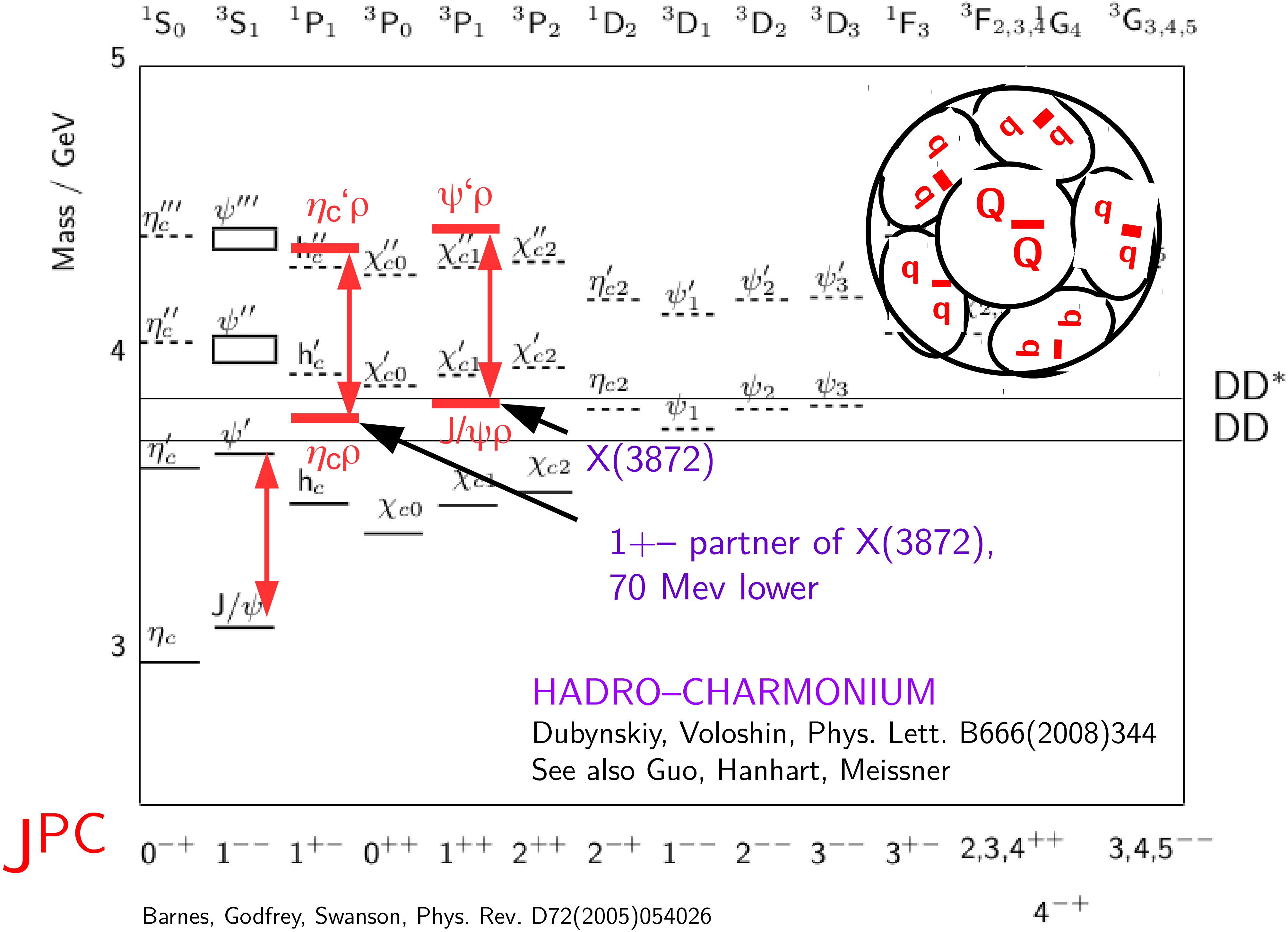


¹S₀ ³S₁ ¹P₁ ³P₀ ³P₁ ³P₂ ¹D₂ ³D₁ ³D₂ ³D₃ ¹F₃ ³F₂,₃,₄ ¹G₄ ³G₃,₄,₅
5
4
3
also (1,2,3) + − and (1,2,3) − +
L=2
Gap, few hundred MeV
L=1
1 − +
Exotic!
~70 MeV
PARTNER !
DD*
DD
HYBRID
Juge, Kuti, Morningstar
Phys. Rev. Lett. 82(1999)4400
Nucl. Phys. Proc. Suppl. 63(1998)3261
see also Zhu; Kou, Pene; Close, Page;
JPC
0−+ 1−− 1+− 0++ 1++ 2++ 2−+ 1−− 2−− 3−− 3+− 2,3,4++ 3,4,5−−
4−+



Barnes, Godfrey, Swanson, Phys. Rev. D72(2005)054026


$^1S_0$ $^3S_1$ $^1P_1$ $^3P_0$ $^3P_1$ $^3P_2$ $^1D_2$ $^3D_1$ $^3D_2$ $^3D_3$ $^1F_3$ $^3F_{2,3,4}$ $^1G_4$ $^3G_{3,4,5}$
Mass / GeV
D*D*
DD*
DD
X(3872)
PION
color neutral
No 0++ D$\bar{D}$ molecule !
(no pion exchange,
forbidden by parity)
MOLECULES
Tornqvist, Phys. Rev. Lett. 67(1991)556
See also Swanson, Rosner, Close;
Guo, Hanhart, Meissner
JPC
0^{-+} 1^{--} 1^{+-} 0^{++} 1^{++} 2^{++} 2^{-+} 1^{--} 2^{--} 3^{--} 3^{+-} $2,3,4^{++}$ $3,4,5^{--}$
4^{-+}



Barnes, Godfrey, Swanson, Phys. Rev. D72(2005)054026

HUNTING THE 0^{++}

Tetraquark „ground state“ ~3700

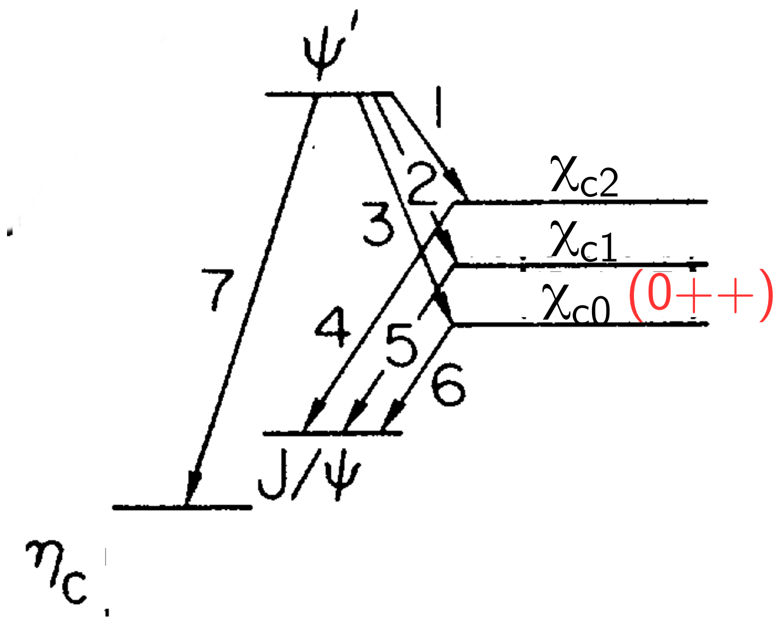
Non-existing (?) $D\bar{D}$ molecule ~3770
(one–pion exchange forbidden by parity)

Radiative ψ' decays at CRYSTAL BALL

Radiative transitions
e.g. 1 – – → 0++

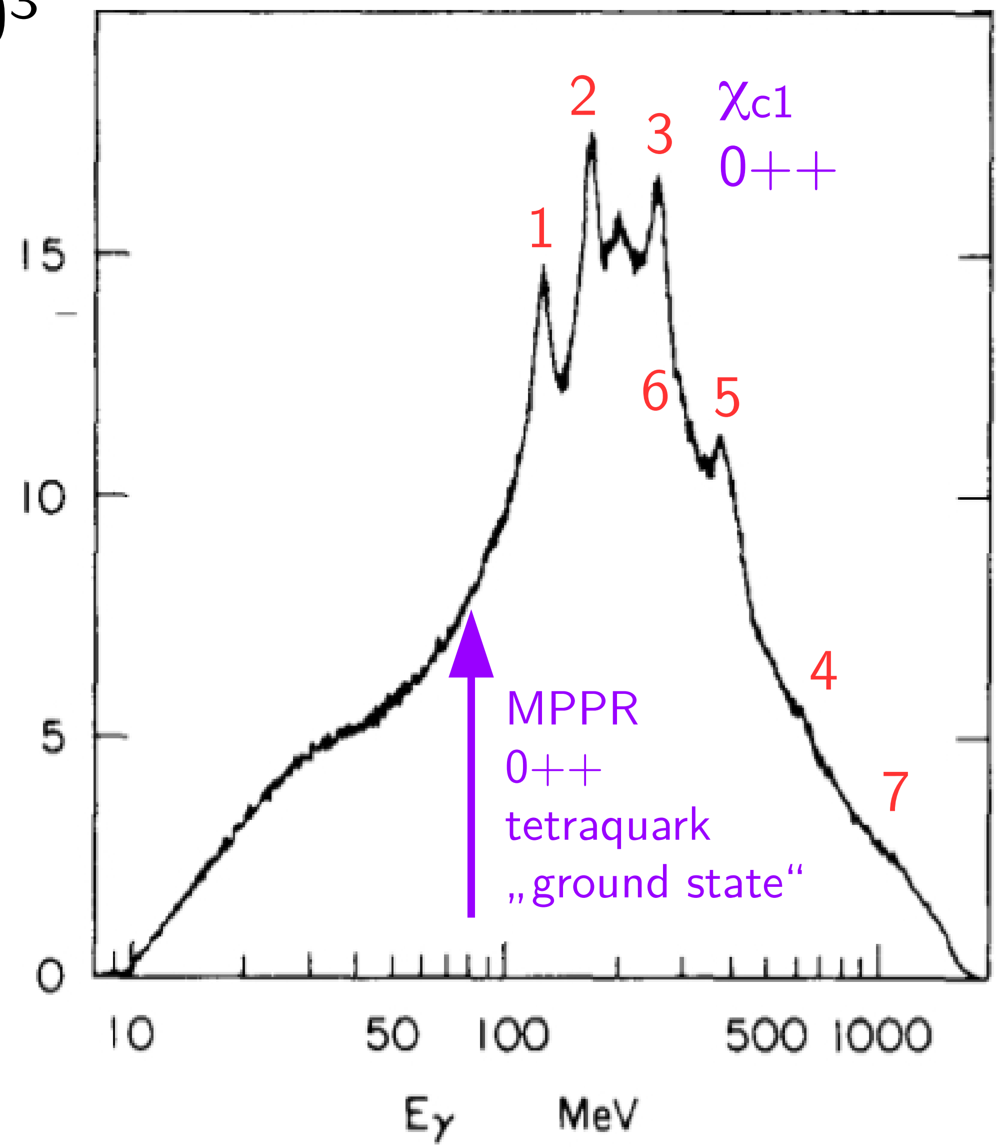
1.8 Mill. ψ' decays

Problem:
suppressed by α_{em}

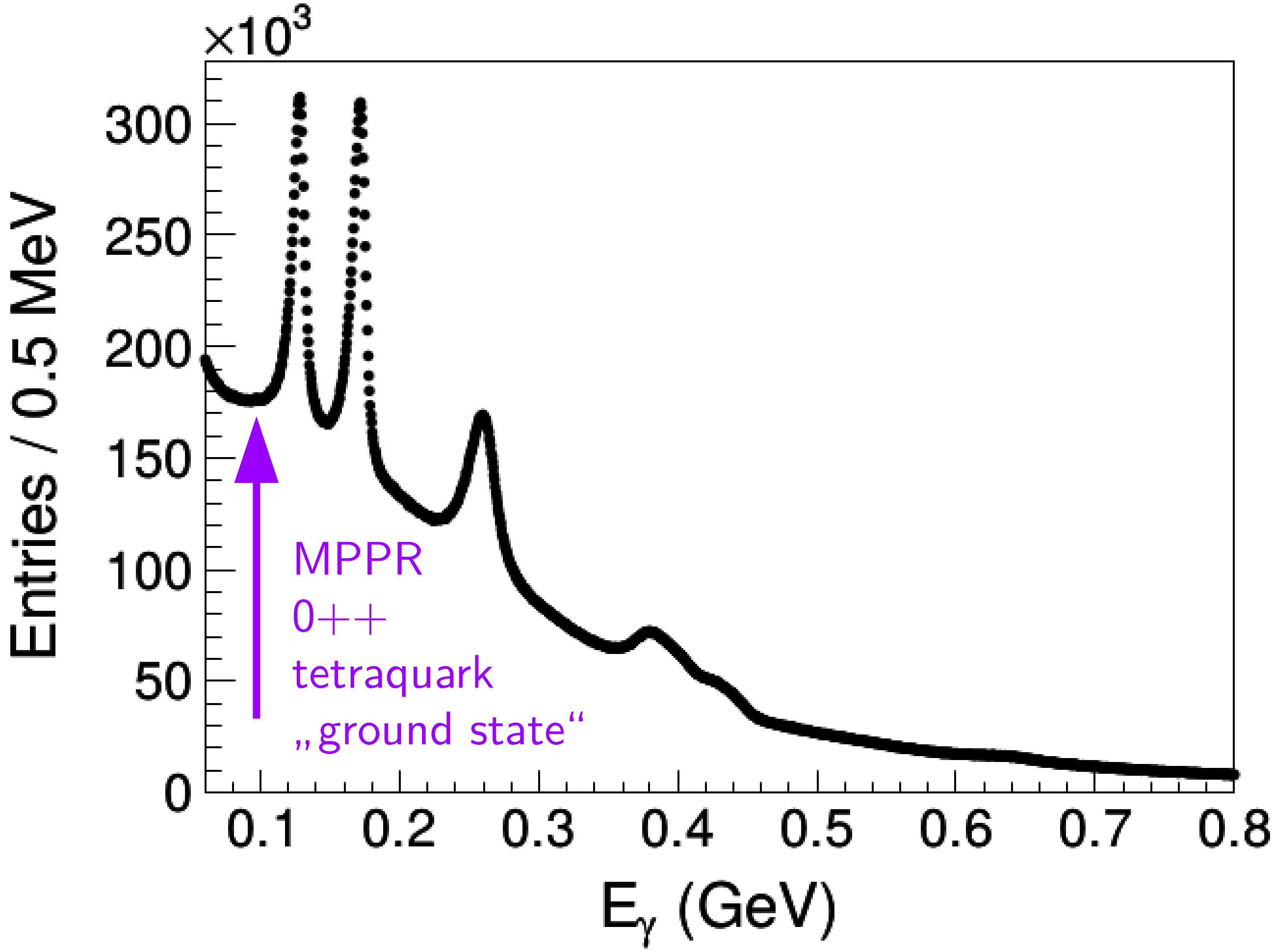


x 10^3

J. Gaiser et al., Phys.Rev. D34 (1986) 711



Radiative ψ‘ decays at BESIII



BESIII, arXiv:1703.00077[hep-ex]
106 Mill. ψ‘ decays
Where are the 0++ tetraquarks ?
450 Mill. ψ‘ decays on tape (2009 and 2012 data)

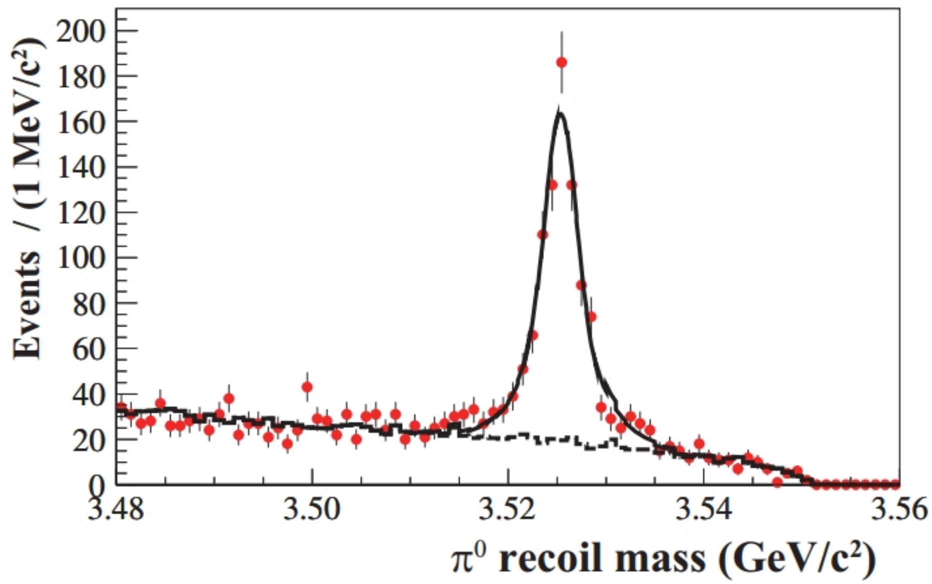
HUNTING THE 1^{+-}

Diquark anti-diquark tetraquark
1^{+-} partner of X(3872), ~20 MeV higher

Hadro–charmonium
1^{+-} partner of X(3872), ~70 MeV lower

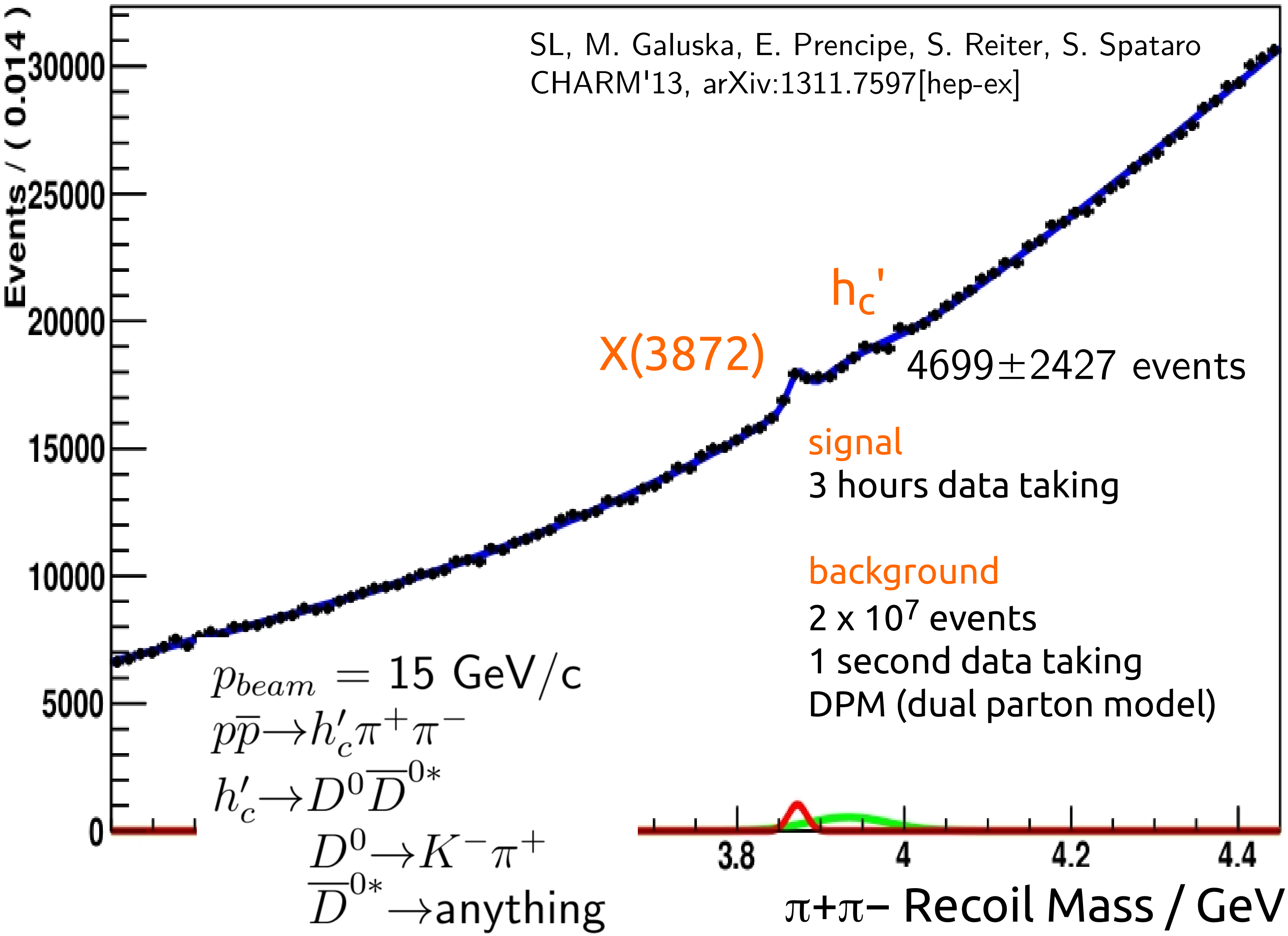
1+− states

- difficult in B decays
  e,g. h_c never seen at Belle
  $0-+ \rightarrow 0-+\ 1+-$
  violates factorisation
- BESIII
  $\psi' \rightarrow \pi^0 h_c$
  violates isospin (BR small)
  $(8.6 \pm 1.3) \times 10^{-4}$
  but still significant yield
- $\bar{\text{P}}$ANDA
  formation $p\bar{p} \rightarrow h_c$ possible
  $(1.27 \pm 0.74) \times 10^6$ events per day
  in startup phase
  our estimate, by detailed balance
  from $\mathcal{B}(h_c \rightarrow p\bar{p})$
  LHCb Eur. Phys. J. C73(2013)2462
- $pp \rightarrow h_c'$
  unobserved yet
  → see next slide



BESIII, Phys. Rev. D 86, 092009 (2012)
tagging on η_c (16 decays)
106 ± 4 mill. ψ' events
832 ± 35 fitted h_c events

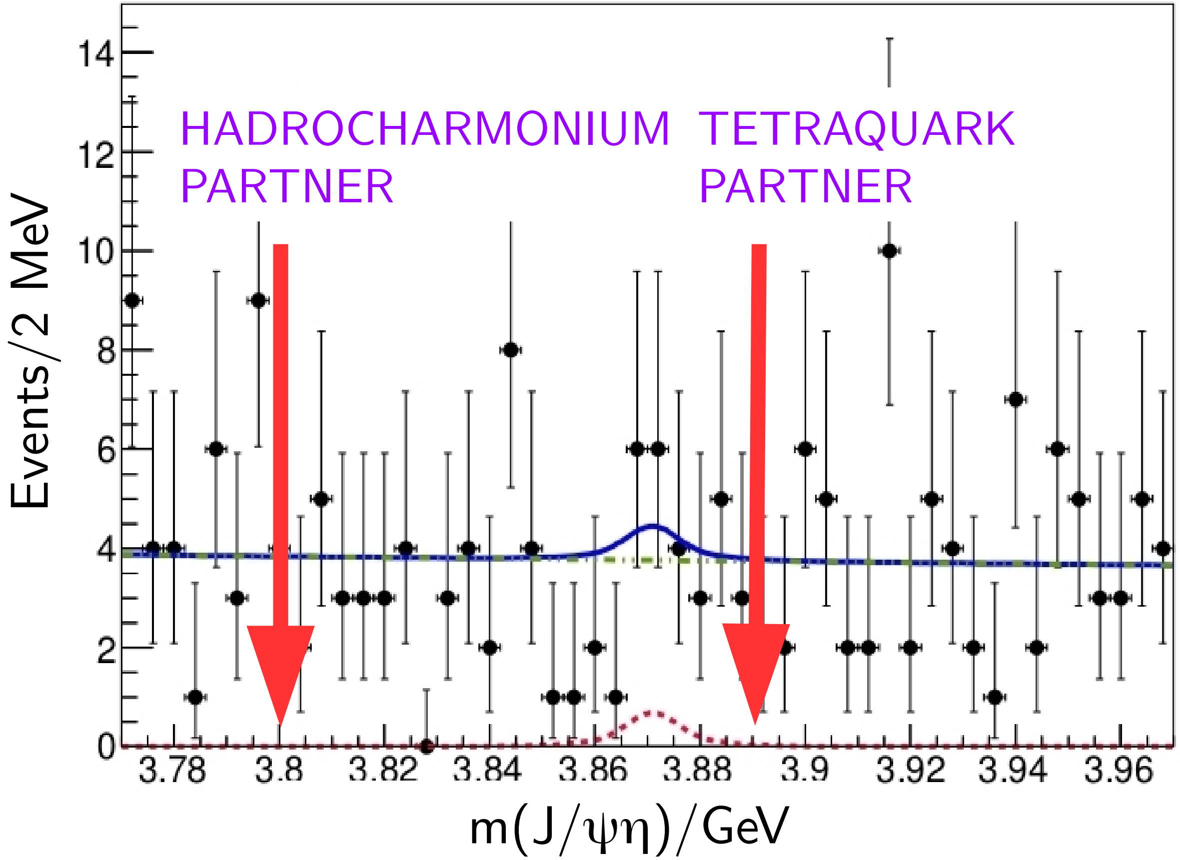
h_c'(1+−) at $\overline{\text{P}}$ANDA (MC)



Direct search for 1+– partner of the X(3872)

$$B^{\pm} \to J/\psi \eta K^{\pm}$$

$\mathcal{B} = (1.24 \pm 0.14) \times 10^{-4}$

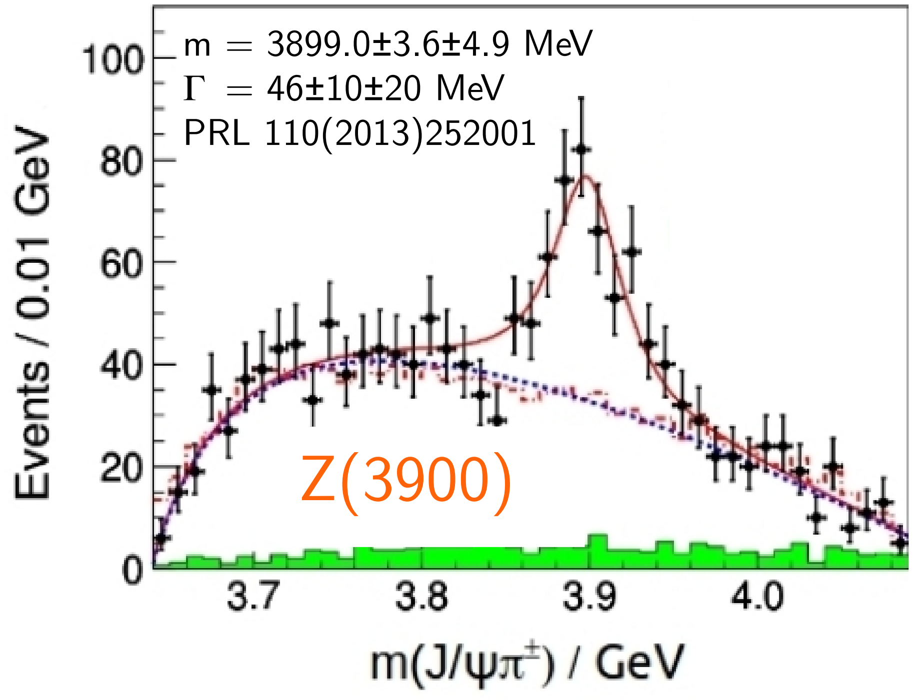


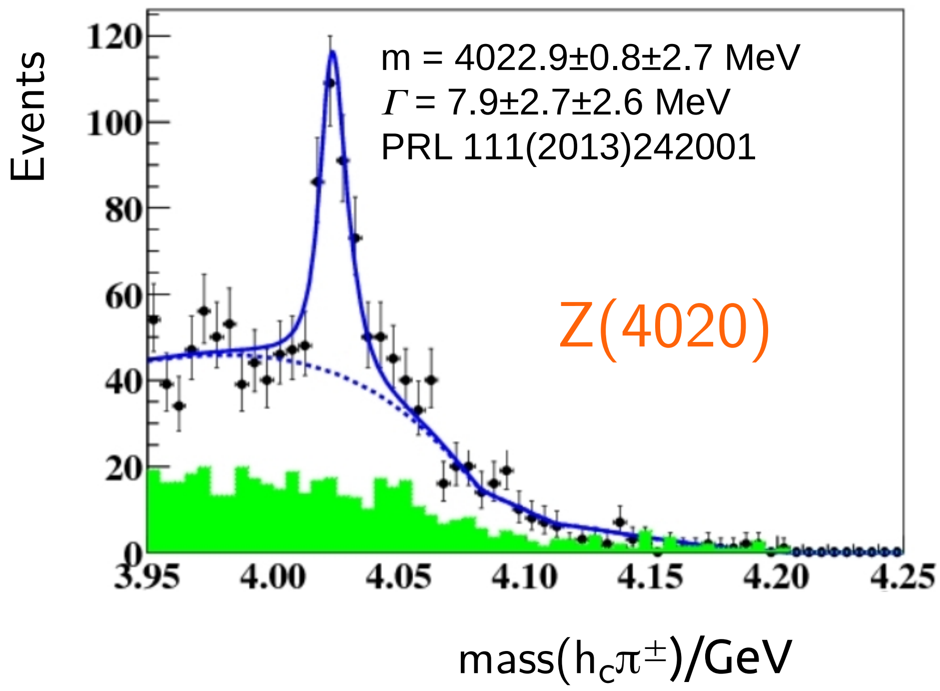
Belle, PTEP 2014(2014)043C01
Belle, Phys. Rev. Lett. 111(2013)032001

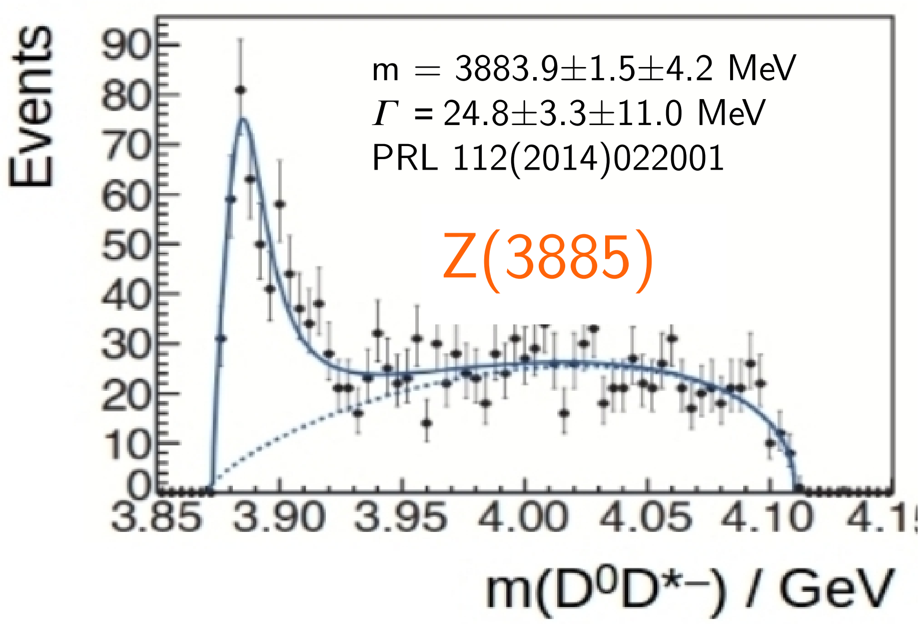
2 photons in η decay → maybe advantage for Belle II
→ plan: integrated luminosity × 50 by ≥2025

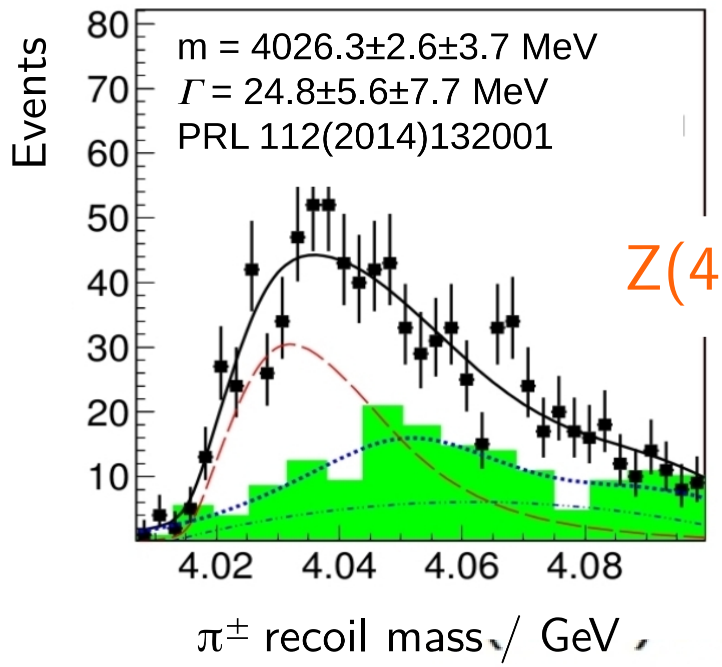
Related:
1 − − (S=1) to 1+ − (S=0)
SPIN–FLIP

Z^+ states at BESIII

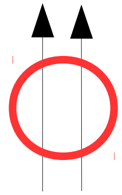








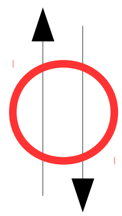
$Z_c(3900)$ decays to $J/\psi\pi$



1– 0– gives 1+
(assuming S-wave, L=0))

Threshold is **$D\bar{D}$***
0– 1– gives 1+

$Z_c(4020)$ decays to $h_c\pi$



1+ 0– gives 1–
(assuming S-wave, L=0)

Threshold is **$D^*\bar{D}^*$**
1– 1– gives 0+,1+,2+

Z DOUBLET

$Z_c(4020, 4025)$ — 1–, $S_{cc}=0$

$Z_c(3900, 3885)$ — 1^+, $S_{cc}=1$

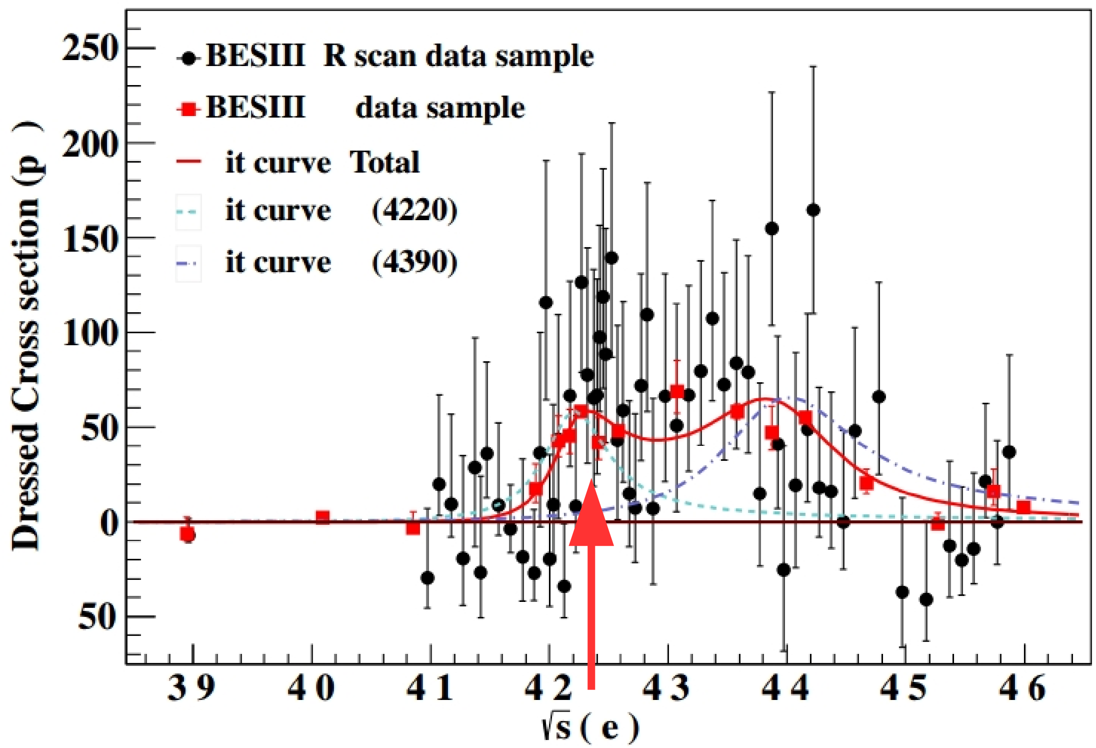
?

requires L=1 ! P-wave decay, maybe with heavy spin-flip ?

THRESHOLD EFFECTS MUST BE S-WAVE !

$e^+e^- \to \pi^+\pi^- h_c$

BESIII, Phys. Rev. Lett. 118, 092002 (2017)



Y(4260) decays to $J/\psi(S=1)\pi\pi$ and to $h_c(S=0)\pi\pi$?

Heavy quark spin-flip !

→ disfavors hybrid

→ disfavors hadro-charmonium

Acknowledgement: this holy grail by Christoph Hanhart.

1++ and 1− −
in the same data
→ B decays

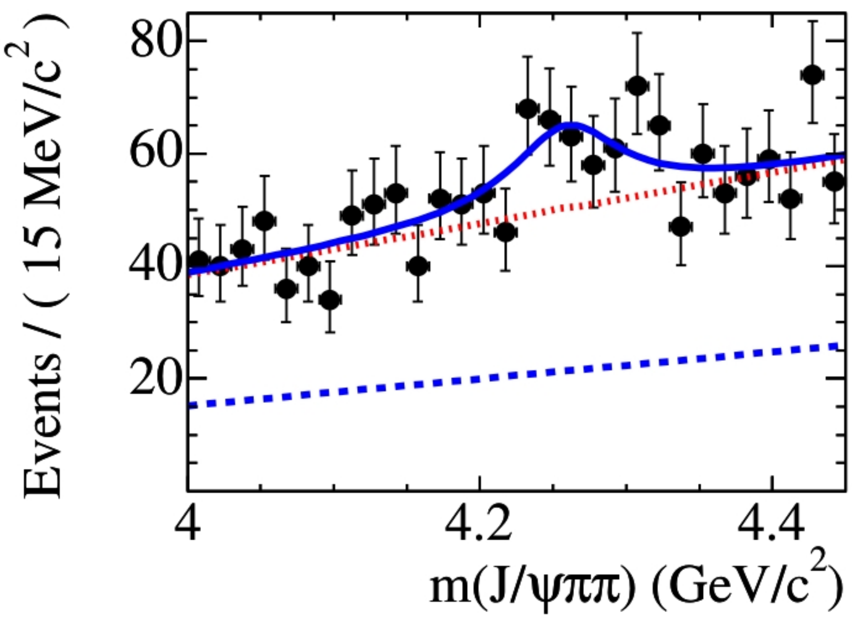
1++ and 1– –

- X(3872) is seen in radiative decays of Y(4260)
  BESIII, Phys. Rev. Lett. 112(2014)092001

- X(3872) is seen in *B* decays

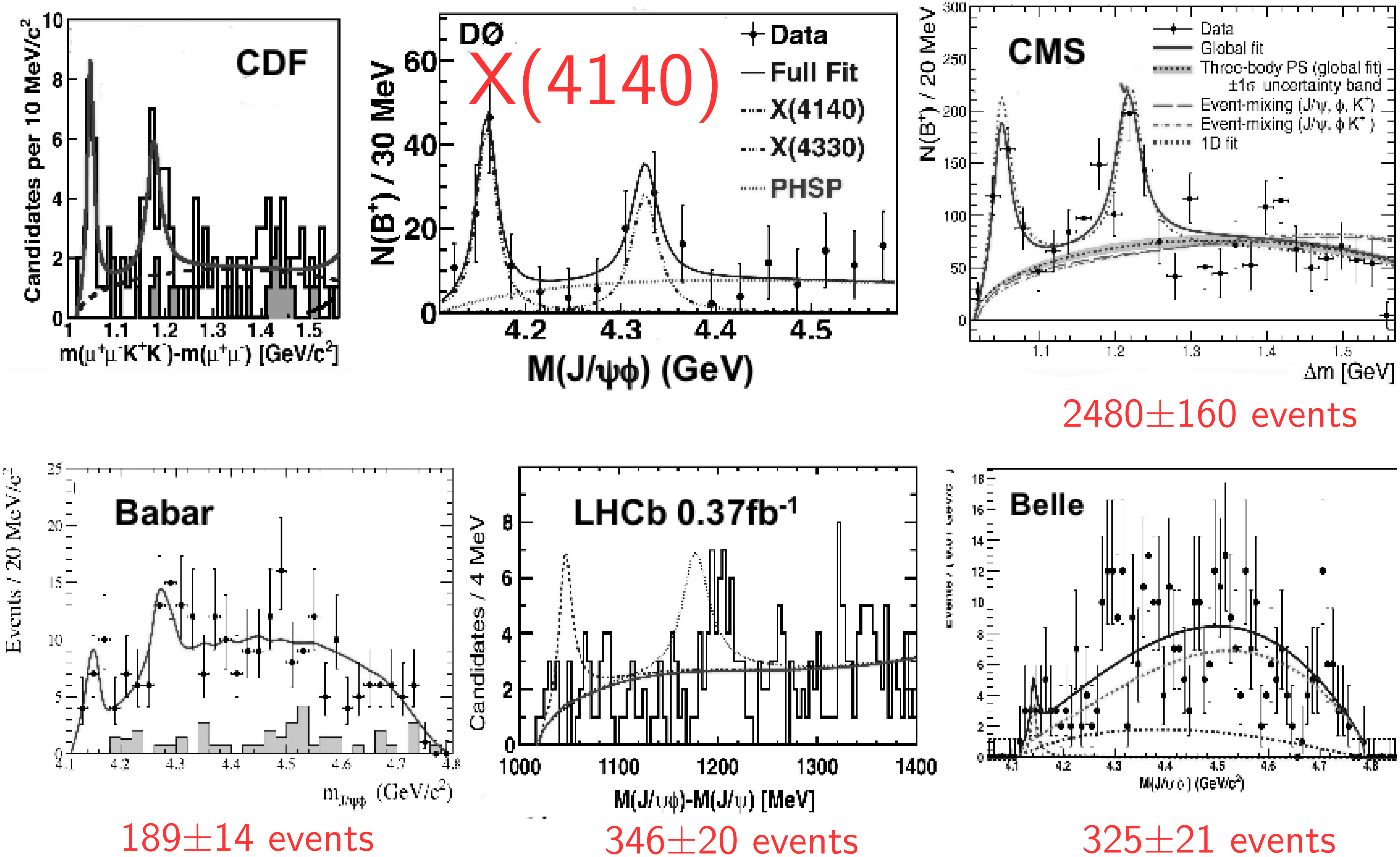
- natural to assume:
  also Y(4260) should be seen in *B* decays
  $\mathcal{B} < 2.9 \times 10^{-5}$
  Belle II, assume 40 fb^{-1} per day
  ~10% reconstruction efficiency
  → ~34 days !

- And: if Y(4260) is a hybrid,
  there should be a 1++ partner to 1 – –
  (~70 MeV lower)



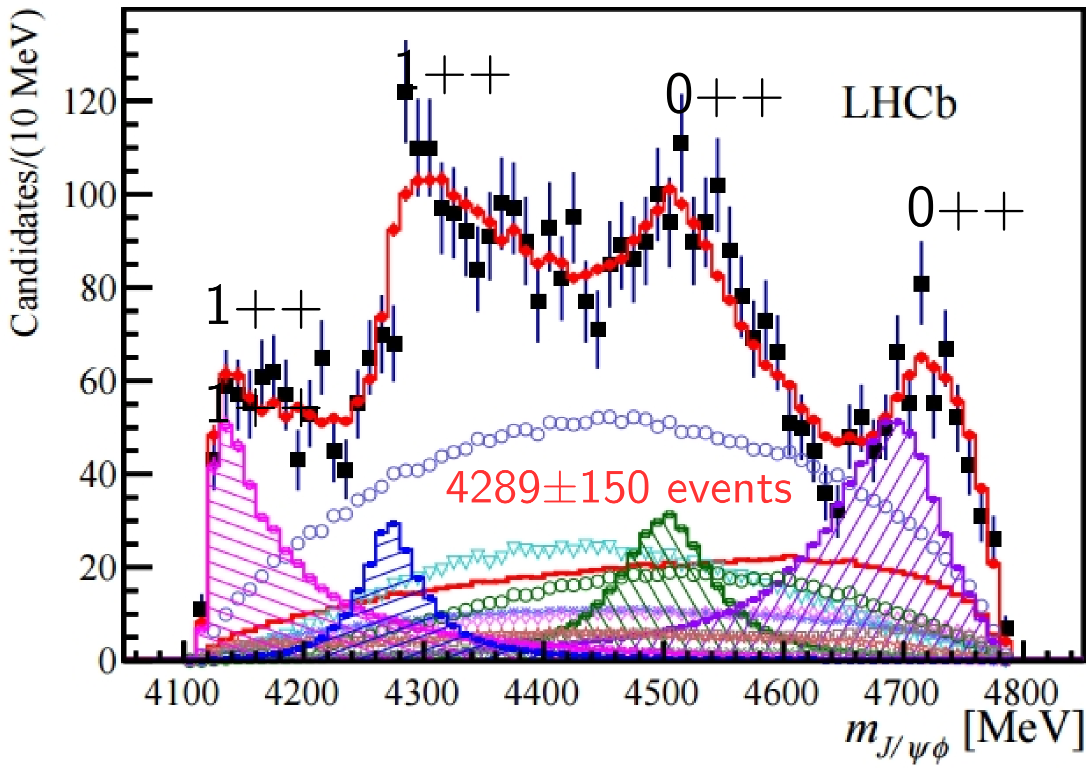
Only search up to data
BaBar, Phys.Rev.D73(2006)011101
211 fb^{-1}
(~1/2 of BaBar data,
~1/5 of BaBar+Belle data)

More 1++: J/ψφ [$c\bar{c}s\bar{s}$] in *B* decays



Sheldon Stone, Recontres de Blois 2016

More 1++: J/ψφ [c$\bar{c}$s$\bar{s}$] in *B* decays



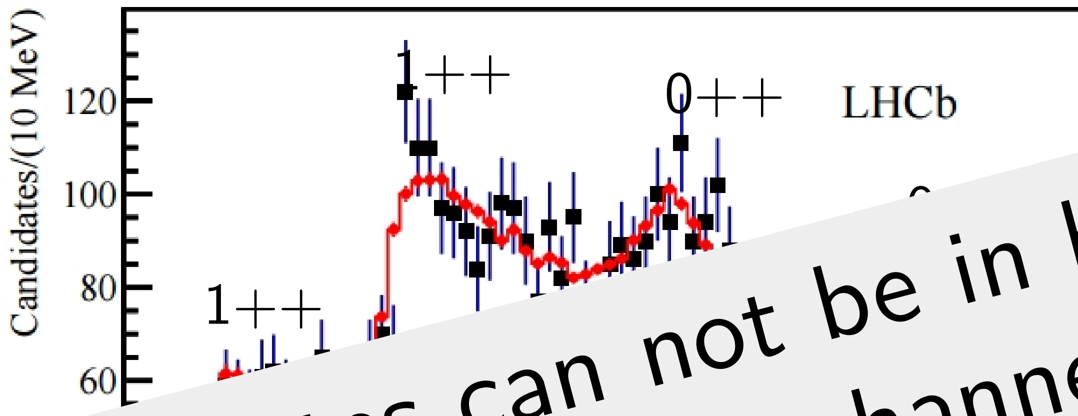
LHCb, Phys. Rev. Lett. 118(2017)022003

LHCb, Phys. Rev. D95(2017)012002

- 1++ doublet → problem for diquark anti-diquark tetraquarks
  solution: interpret X(4140) as threshold effect
- J/ψφ hadro–charmonium: doublet o.k., but
  - sequence should be 0++, 1++, 0++, 1++
  - m(J/ψ)+m(φ)= 4116 MeV → positive „binding energy“ (~20 MeV)
- molecules ? → no isospin! → η exchange

Karliner, Rosner, Nucl. Phys. A 954(2016)365

More 1++: J/ψφ [$c\bar{c}s\bar{s}$] in *B* decays



C=−1 states can not be in here!

Need another decay channel,

$D_s\bar{D}_s^*$, $D_s\bar{D}_{sJ}$

$D_{sJ}(2317)$ not seen at LHCb

maybe advantage for Belle II

- 1++ c… …quarks
  solutic… …ect
- J/ψφ ha… …o.k., but
  - sequen… …0++, 1++, 0++, 1++
  - m(J/ψ)+m(φ)= 4116 MeV → positive „binding energy"
- Molecules ? → no isospin! → η exchange

Karliner, Rosner, Nucl. Phys. A 954(2016)365

Upper limit on X(4140)
Belle $\mathcal{B}$<6 x 10^{-6} at 90% CL

2016/17: factor ~10 more B mesons
(CMS and LHCb)

$\rightarrow$ entering $\mathcal{B}\sim 10^{-7}$ regime
$\rightarrow$ new observations

SUMMARY

BESIII 1^{+-}

0^{++} $\overline{\text{P}}$ANDA

1^{++} and 1^{--}

Belle II LHCb

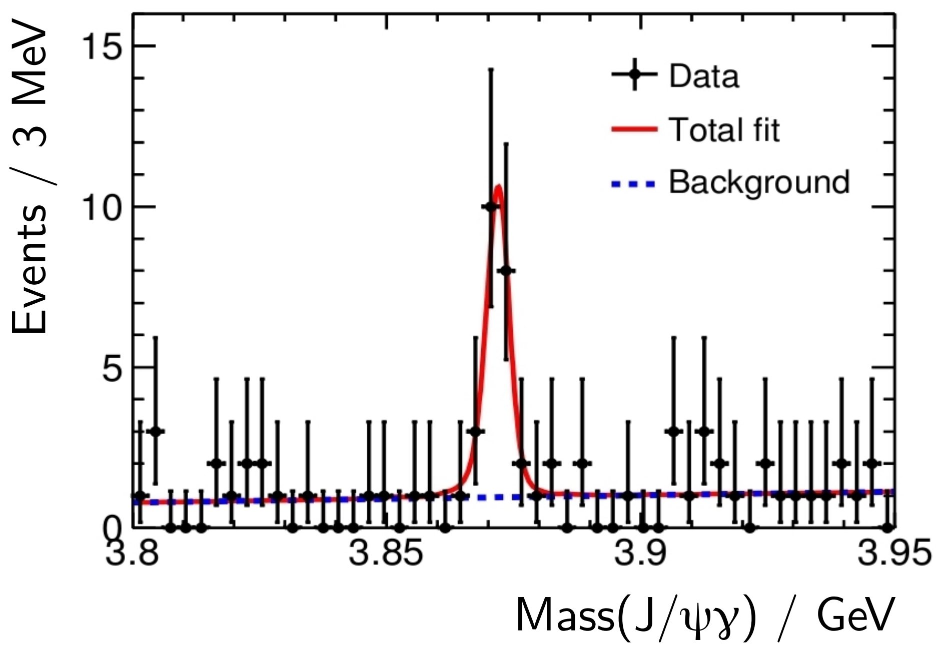
Acknowledgement to Changzheng Yuan.

THANK YOU.

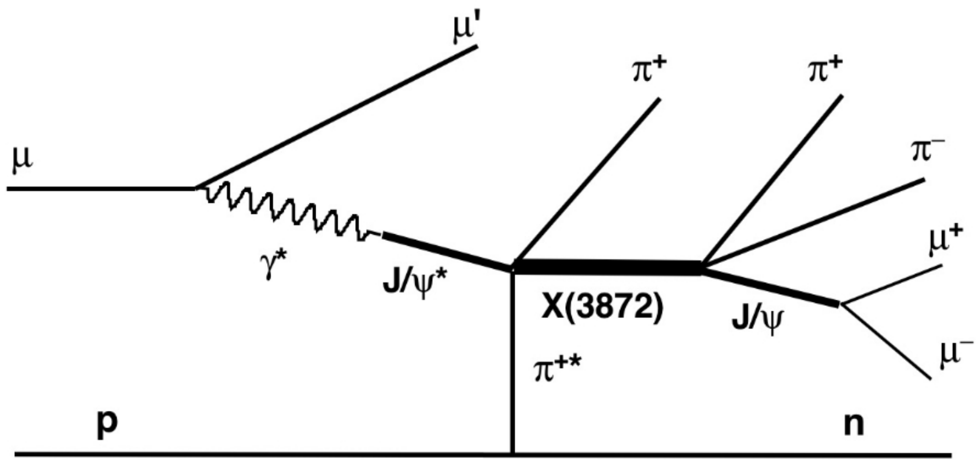
BACKUP

The connection between the X and the Y
$e^+e^- \to Y(4260) \to X(3872)\,\gamma$

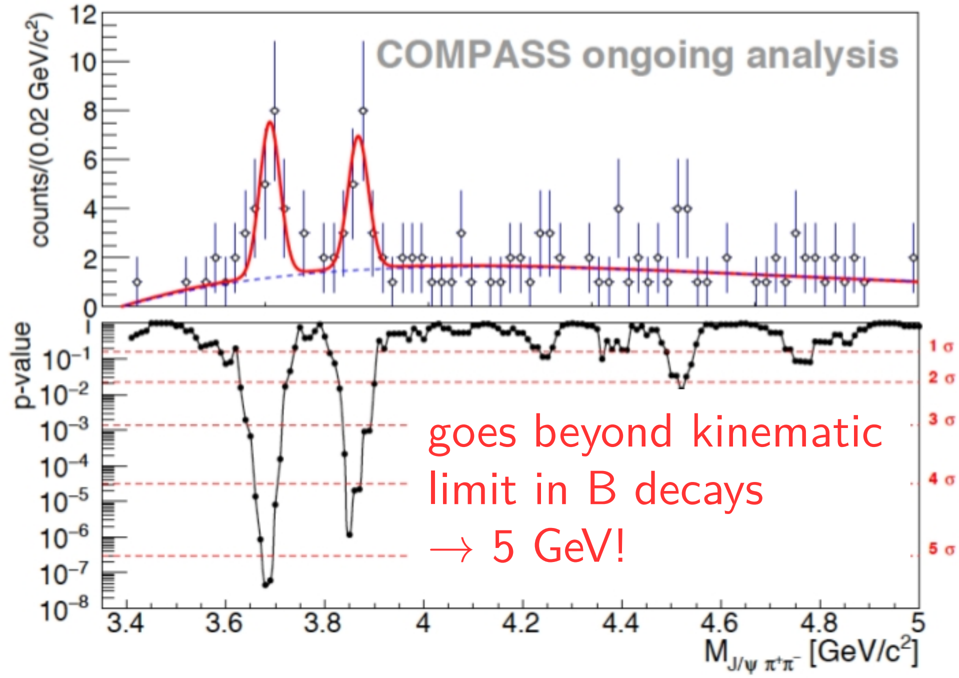
BESIII, Phys. Rev. Lett. 112(2014)092001



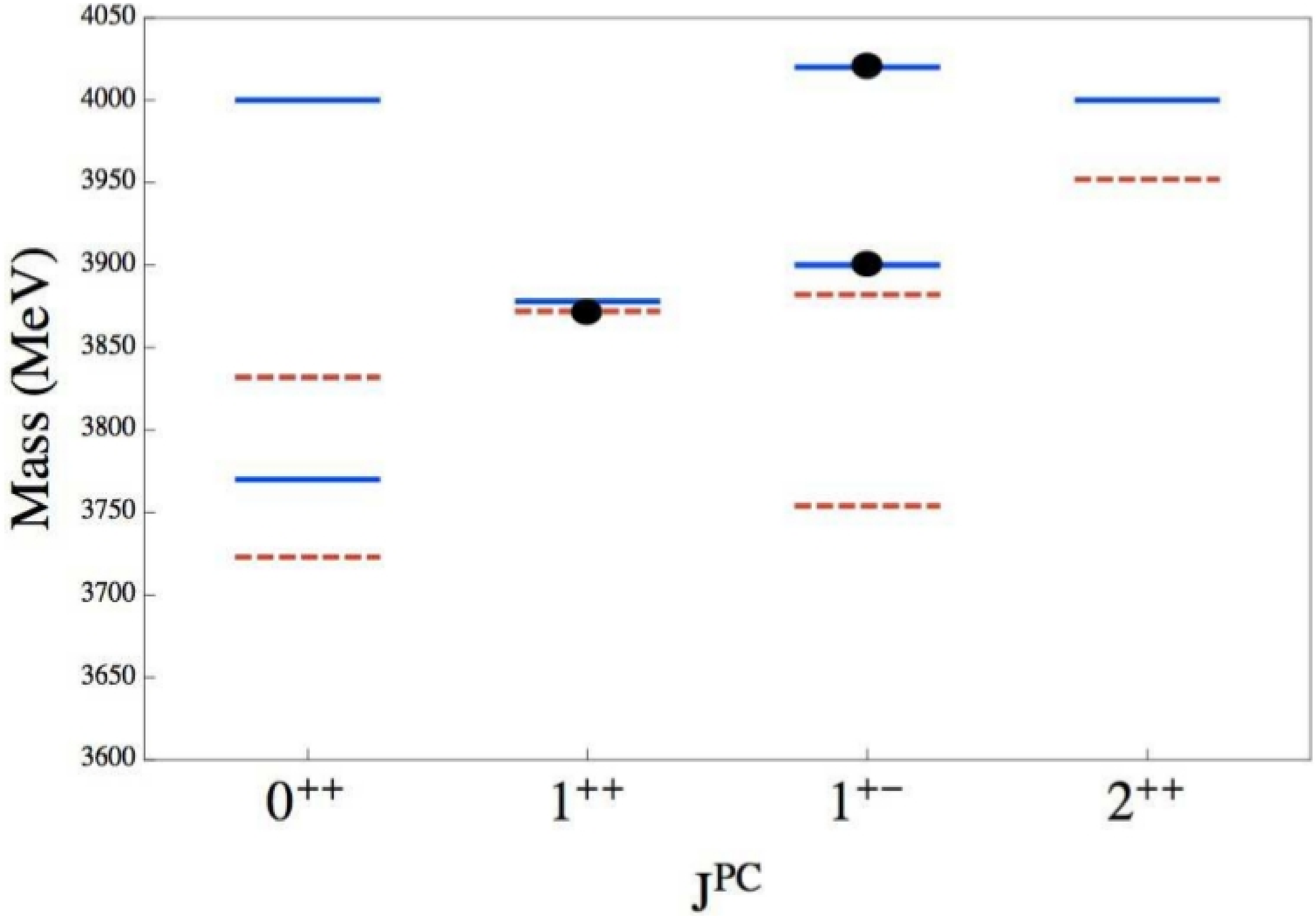
NEW! COMPASS – Photoproduction of X(3872)



Muon data of 2003-2010
$N_{\psi(2S)} = 16.1 \pm 5.2$
$N_{X(3872)} = 13.9 \pm 4.9$
$\sigma_M = 20.6 \pm 6.1$ MeV



COMPASS Preliminary
J. Bernhard, BARYON'16
A. Gridin, 121th JINR Scientific Council



Maiani, Piccinini, Polosa, Riquer („MPPR“)
Phys.Rev. D89 (2014) 114010

SuperKEKB asymmetric B meson factory, e+ e− → $B\bar{B}$

adjusted to Υ(4S) resonance, $\sqrt{s}$=10.6 GeV

different beam energies

8 GeV → 7 GeV (lower emittance)

3.5 GeV → 4 GeV (Touschek lifetime)

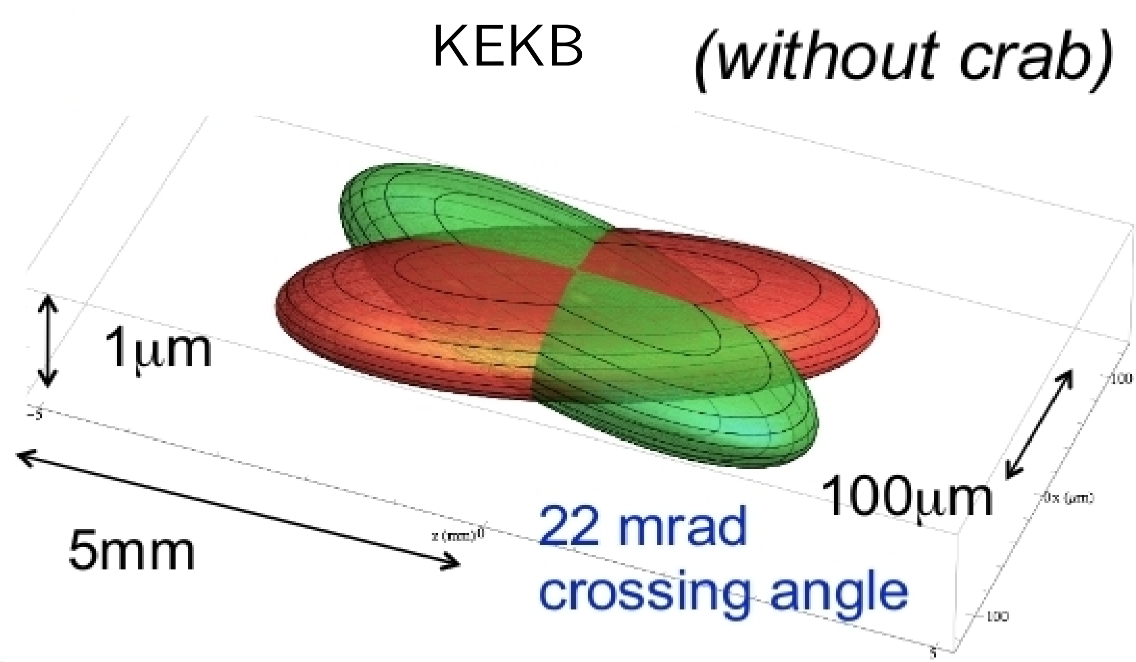
Upgrade: luminosity peak x40, integrated x50

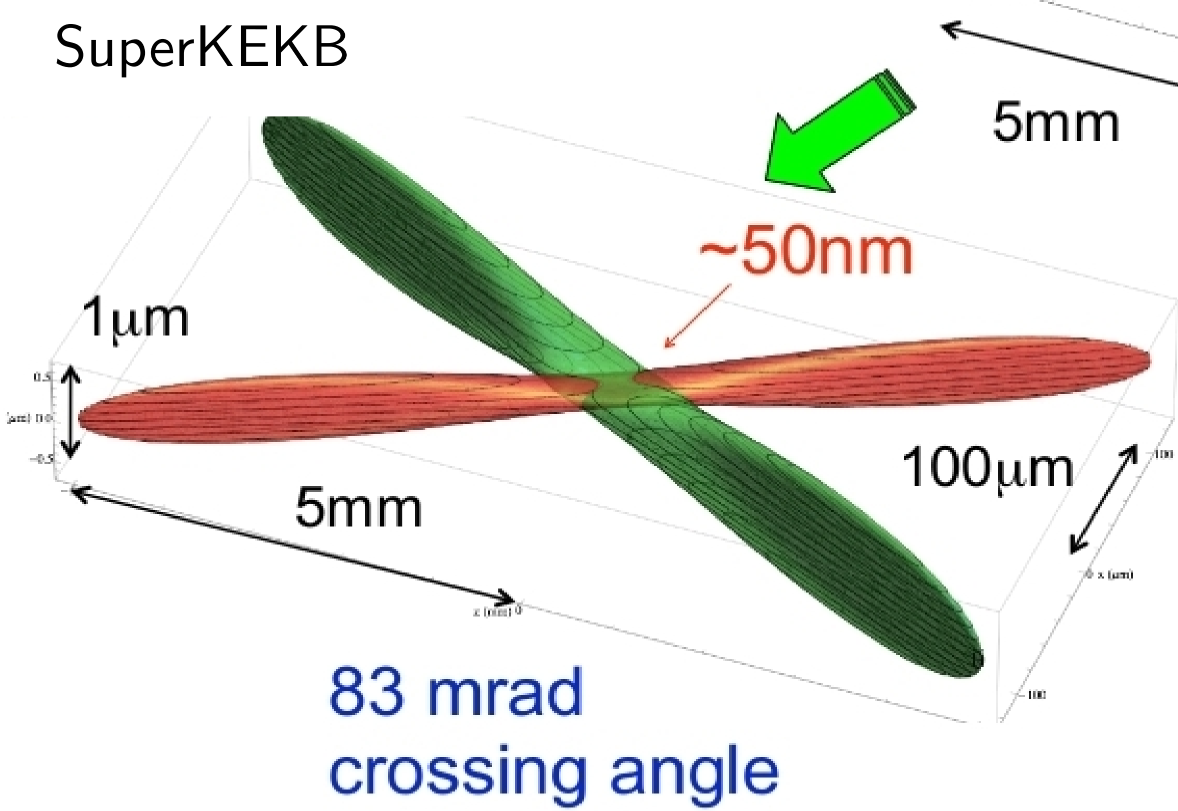
Nano-Beam Scheme

Belle → Belle II

Luminosity x 40

$L \leq 0.8 \times 10^{36}\ cm^{-2}\ s^{-1}$





originally proposed for SuperB
by P. Raimondi (INFN)

graphics E. Paoloni (Pisa)

KEK Inter-University Research Institute Corporation
High Energy Accelerator Research Organization

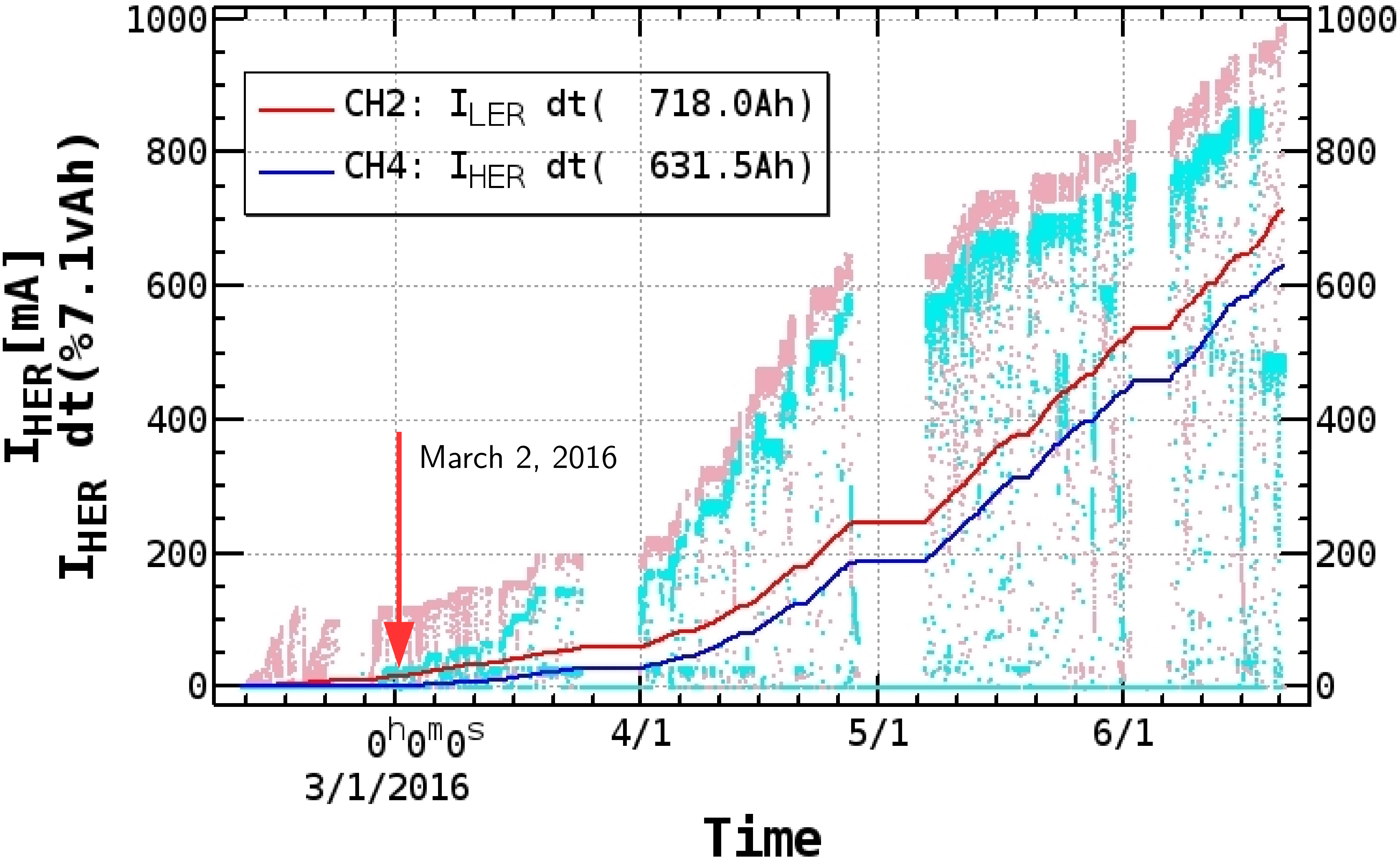
Press Release

First turns and successful storage of beams in the SuperKEKB electron and positron rings

March 2nd, 2016

High Energy Accelerator Research Organization (KEK)

June 21, 2016: LER beam current exceeded 1 Ampere



Belle II XYZ reach

assume 50 ab^{-1} ($\geq$2024)

State	Production and Decay	N
X(3872)	$B \to K X(3872)$, $X(3872) \to J/\psi \pi^+ \pi^-$	$\simeq$14400
Y(4260)	ISR, $Y(4260) \to J/\psi \pi^+ \pi^-$	$\simeq$29600
Z(4430)	$B \to K^{\mp} Z(4430)$, $Z(4430) \to J/\psi \pi^{\pm}$	$\simeq$10200

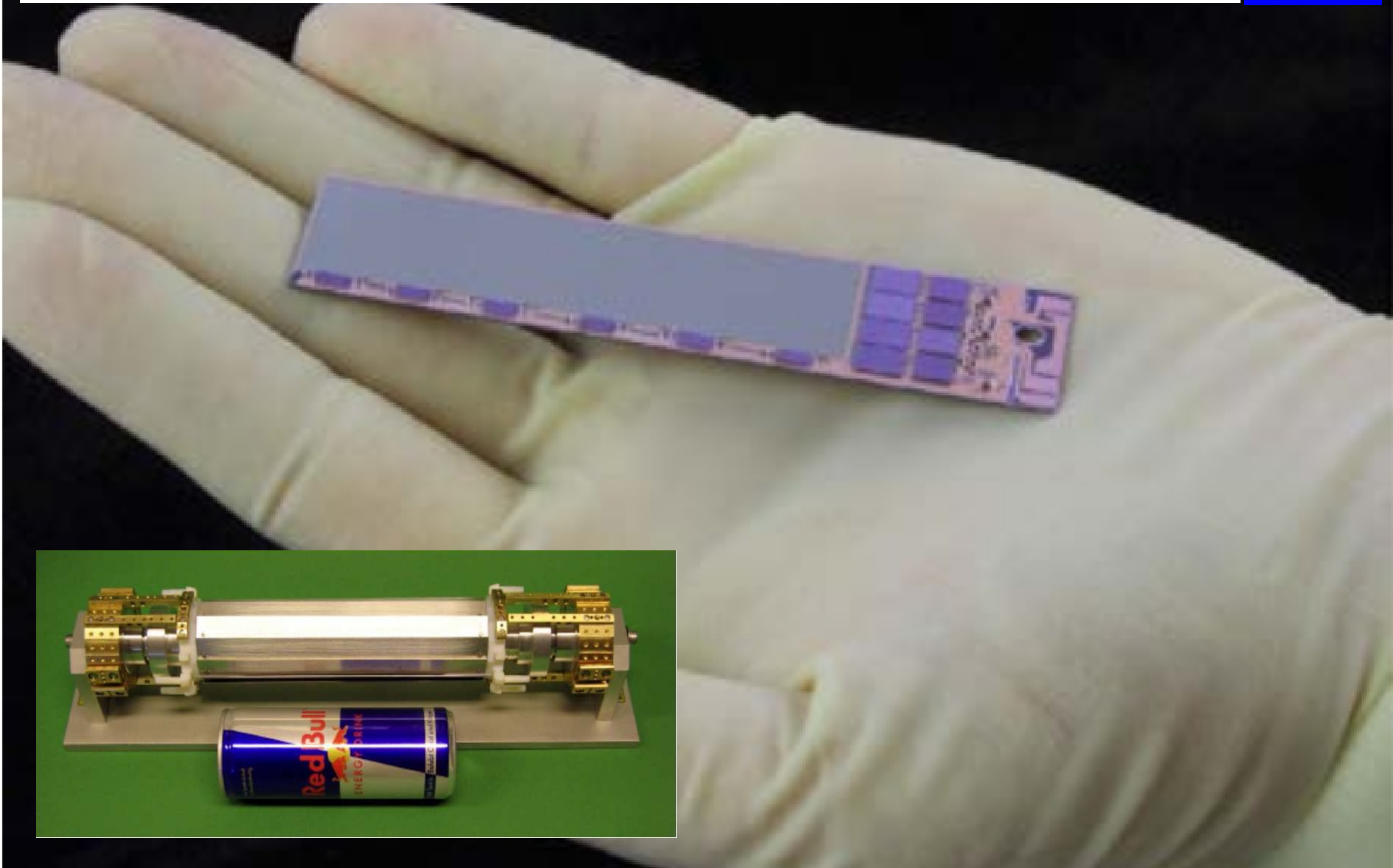
$\to$ search for rare decays feasible

same number of X(3872):

- LHCb (upgrade) with $\geq$40 fb^{-1} (2026?)
  (assume no change in trigger efficiency)
- PANDA $\simeq$20 days ($p\bar{p} \to X(3872)$)

Belle II DEPFET Pixel Detector

Univ. Bonn, DESY, Univ. Giessen, Univ. Göttingen, Univ. Hamburg, Univ. Heidelberg,
KIT Karlsruhe, Univ. Mainz, HLL München, MPI München, LMU München, TU München



P-wave tetraquarks

In the diquark anti-diquark model.

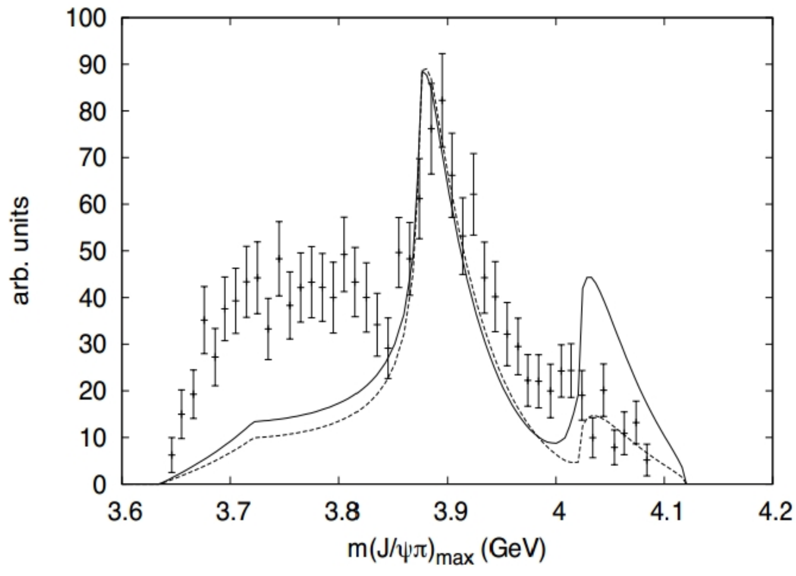
Label	J^{PC}	$\|s_{qQ}, s_{\bar{q}\bar{Q}}; S, L\rangle_J$	$\|s_{q\bar{q}}, s_{Q\bar{Q}}; S', L'\rangle_J$	Mass
Y_1	1^{--}	$\|0,0;0,1\rangle_1$	$(\|0,0;0,1\rangle_1 + \sqrt{3}\|1,1;0,1\rangle_1)/2$	$M_{00} - 3\kappa_{qQ} + B_Q$
Y_2	1^{--}	$(\|1,0;1,1\rangle_1 + \|0,1;1,1\rangle_1)/\sqrt{2}$	$\|1,1;1,L'\rangle_1$	$M_{00} - \kappa_{qQ} + 2a + B_Q$
Y_3	1^{--}	$\|1,1;0,1\rangle_1$	$(\sqrt{3}\|0,0;0,1\rangle_1 - \|1,1;0,1\rangle_1)/2$	$M_{00} + \kappa_{qQ} + B_Q$
Y_4	1^{--}	$\|1,1;2,1\rangle_1$	$\|1,1;2,L'\rangle_1$	$M_{00} + \kappa_{qQ} + 6a + B_Q$
Y_5	1^{--}	$\|1,1;2,3\rangle_1$	$\|1,1;2,L'\rangle_1$	$M_{00} + \kappa_{qQ} + 16a + 6B_Q$

Is the $Z_c(3900)$ a kinematical effect ?

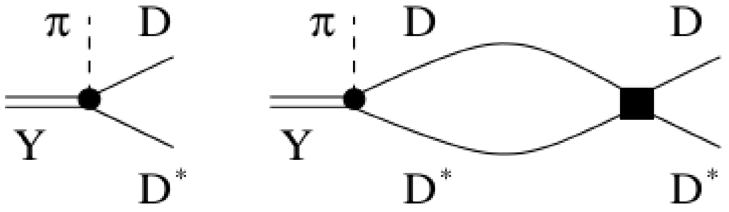
Bugg J. Phys. G35(2008)075005, Phys. Lett. B598(2004)8
Chen et al., Phys. Rev. D84(2011)094003

- threshold opening of a 2nd channel
- channels are „coupled“ (by unitarity of T matrix)
- advantage: lineshape may peak above threshold (although pole below threshold)
- disadvantage:
  - couplings unknown
  - some parameterisations only 1st order (assume small couplings)

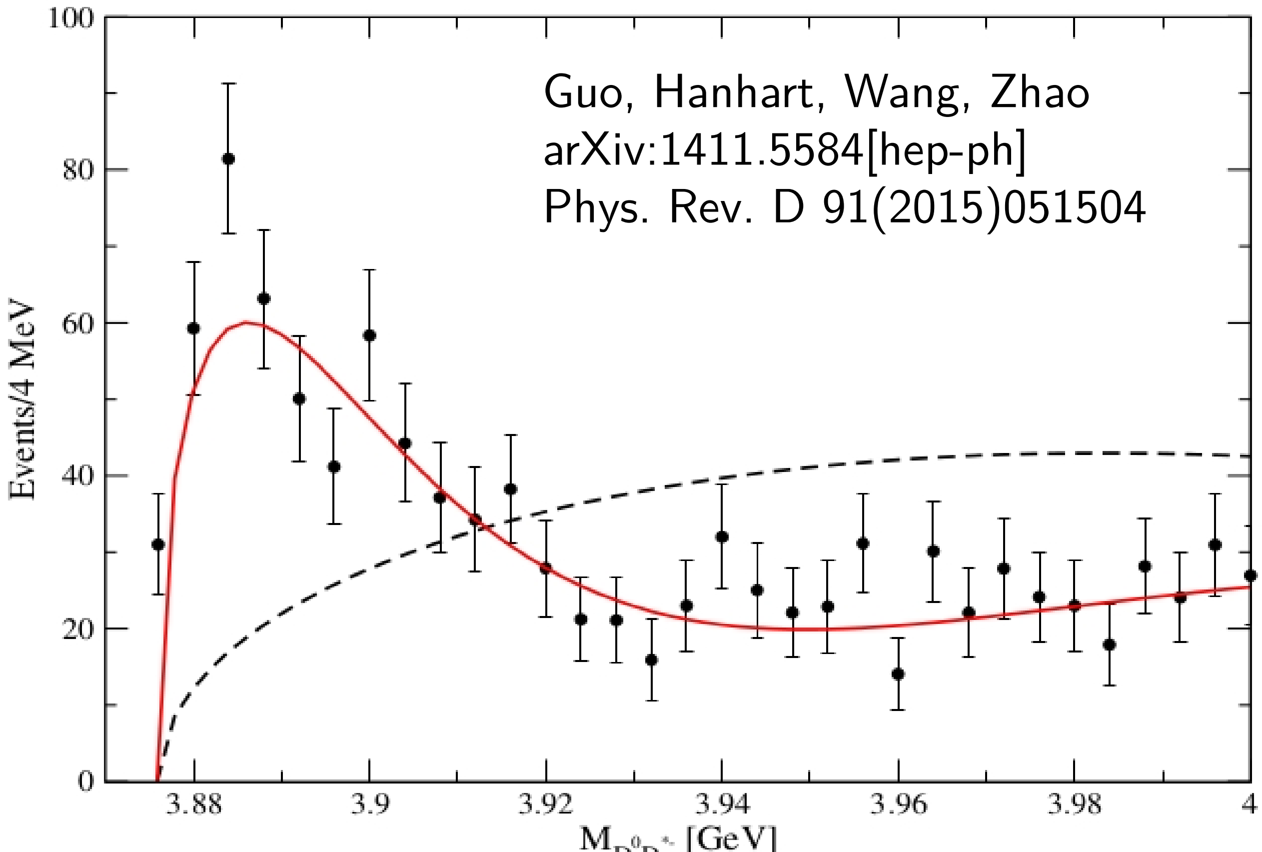
Swanson, PRD 91(2015)034009



Is the $Z_c(3900)$ a kinematical effect ?

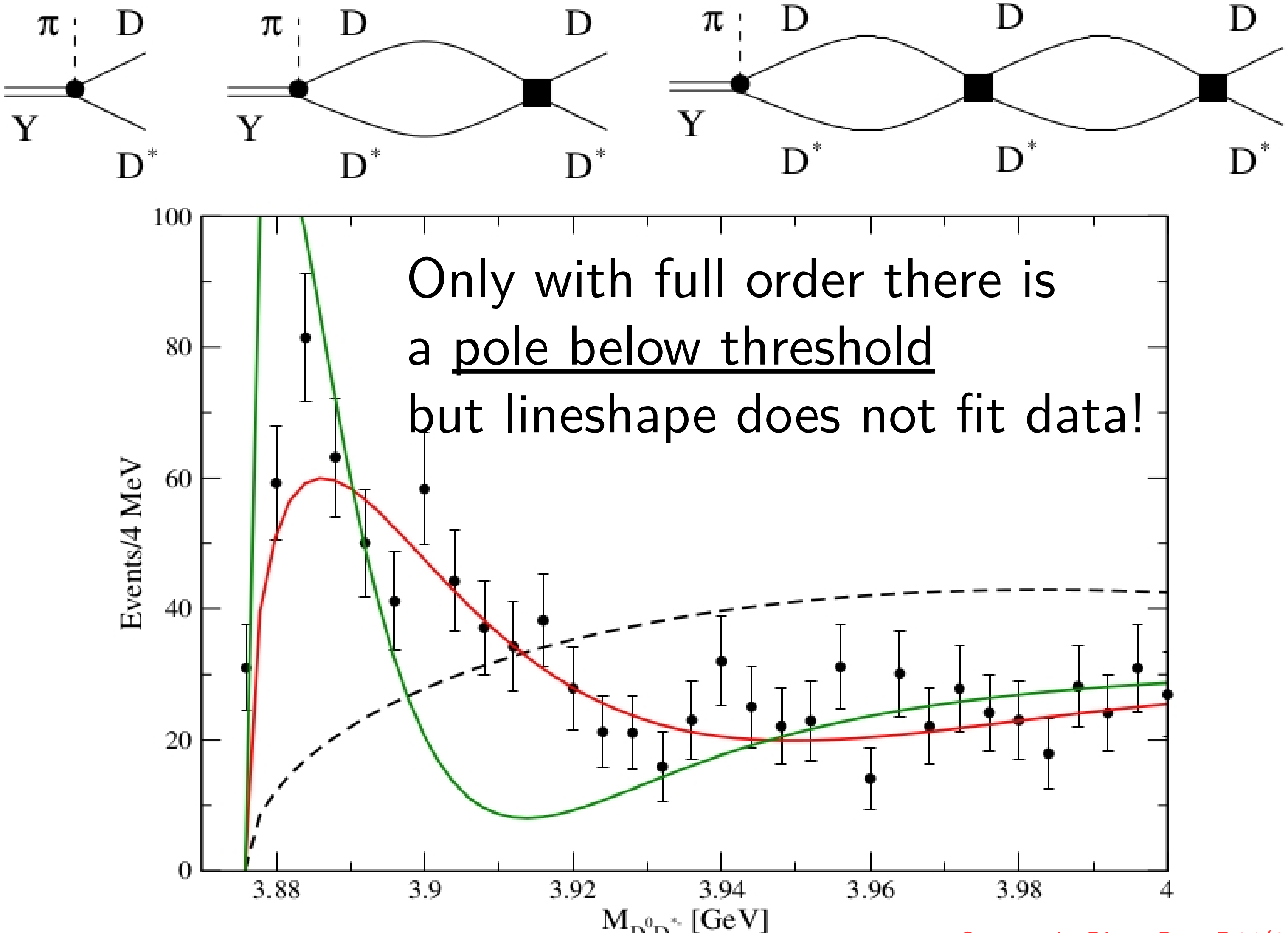


line shape model has 3 free parameters (fitted to data)



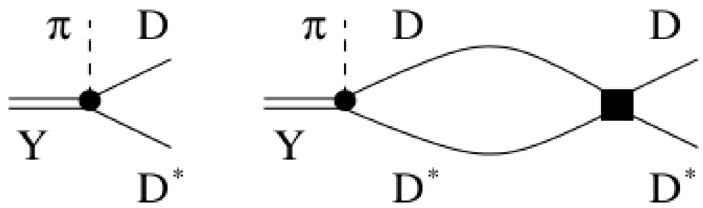
Guo et al., Phys. Rev. D91(2015)051504
slide by C. Hanhart, SCHLECHING'15

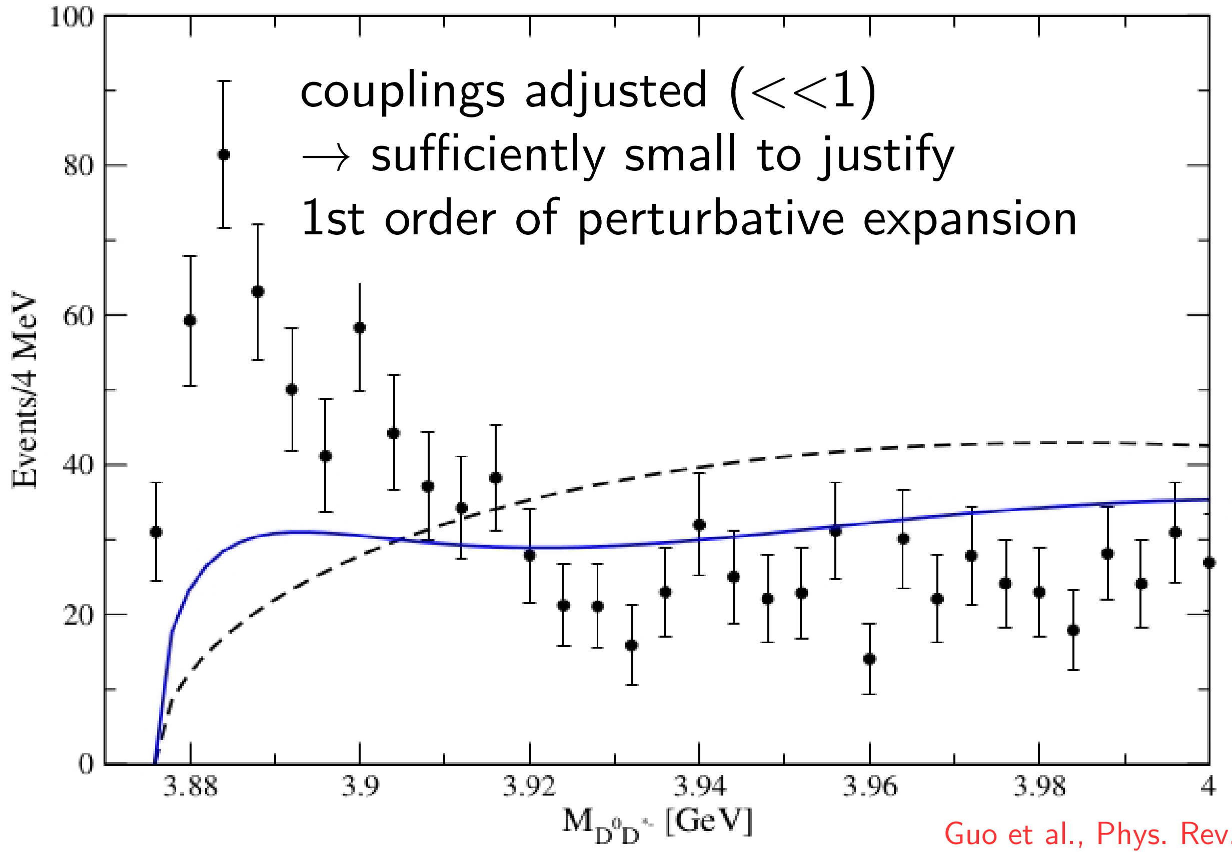
Is the $Z_c(3900)$ a kinematical effect ?



Guo et al., Phys. Rev. D91(2015)051504
slide by C. Hanhart, SCHLECHING'15

Is the $Z_c(3900)$ a kinematical effect ?





Guo et al., Phys. Rev. D91(2015)051504
slide by C. Hanhart, SCHLECHING'15

Where is the J=0 partner of the Y(4260) ?

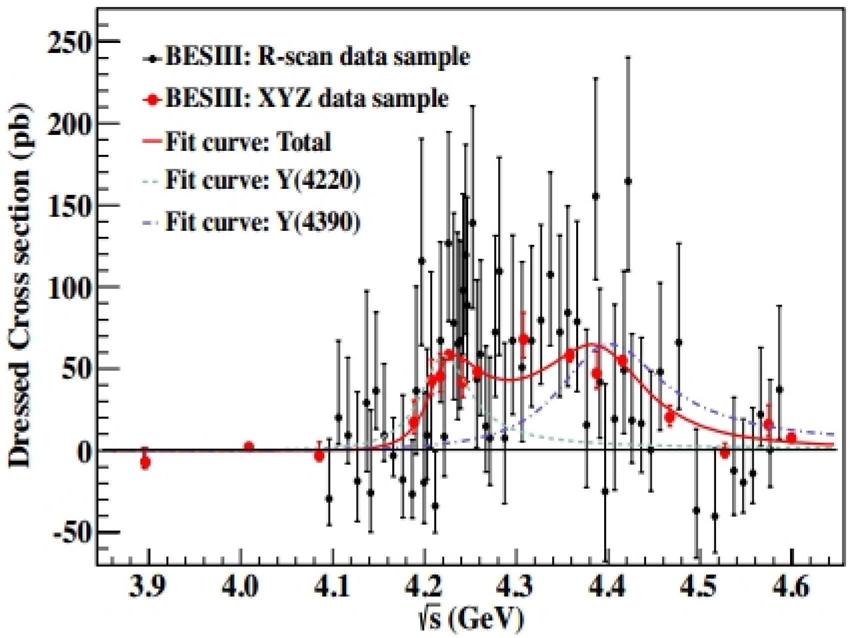
- molecule
  (e.g. Guo, Hanhart, Meißner, Wang, Zhao, PLB 725(2013)127)
  $[DD_1]$ for 1– is the ground state
  $\rightarrow$ mass for $[D^*D_1]$ for 0– would be ~135 MeV higher
- tetraquark (e.g. Burns et al., Phys.Rev. D82 (2010) 074003)
  - L=0 only has positive parity states: 0++ (~3770)
  - L=1 $\rightarrow$ 0–+ would be 100-150 MeV higher (spin-spin forces)
- hadro-charmonium
  $Y(4260) = [J/\psi\ f_0]$
  $[\eta_c\ f_0]$ is 0–+ $\rightarrow$ mass ~120 MeV lower
- hybrid
  e.g. Kou, Pene, PLB631(2005)164
  1– – is $S_{cc}=0$, $L_{cc}=0$, $L_{gluon}=1$,
  0–+ would be $S_{cc}=1$, $L_{cc}=1$, $L_{gluon}=0$, ~500 MeV higher

$\rightarrow$ search in radiative transistions

$$\sigma(m) = \left| B_1(m)\sqrt{\frac{P(m)}{P(M_1)}} + e^{i\phi} B_2(m)\sqrt{\frac{P(m)}{P(M_2)}} \right|^2$$

$B_i(m)$: constant width Breit-Wigner function
$P(m)$: 3-body phase space factor
ϕ: relative phase between two resonances

significance of two structures assumption over one structure > 10 σ



	M (MeV)	Γ_{tot} (MeV)	Γ_{ee}•Br (eV)	ϕ (rad)
Y(4220)	4218.4±4.0±0.9	66.0±9.0±0.4	4.6±4.1±0.8	--
Y(4390)	4391.6±6.3±1.0	139.5±16.1±0.6	11.8±9.7±1.9	3.1±1.5±0.2

NEW! BESIII Preliminary, Jianming Bian, QWG'16

Y(4260)

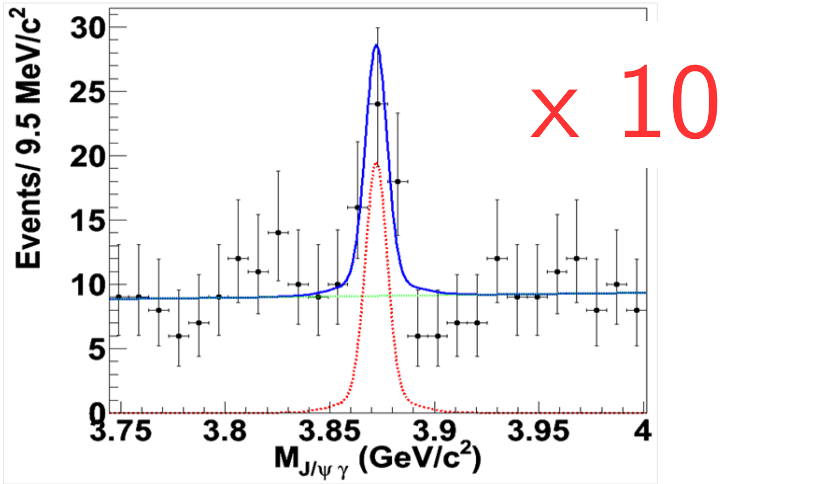
h_c pi+ pi-
(4218.4+5.5−4.5 ± 0.9) MeV
(66.0+12.3−8.3 ±0.4) MeV

J/psi pi+ pi-, BESIII
(4222.0 ± 3.1 ± 1.4) MeV
(44.1 ± 4.3 ± 2.0) MeV

J/Psi pi+ pi-, PDG
4251 ± 9 MeV
120 ± 12 MeV

Prospect for X(3872) at Belle II

- yield of $X(3872) \to J/\psi\pi^+\pi^-$ in 2020-21 (assume 10 ab^{-1}) will be about Belle I yield of $\psi' \to J/\psi\pi^+\pi^-$
- if $\Gamma_{X(3872)} > 0.23$ MeV (bias) the width of the X(3872) can be measured with a systematic error of $\pm$110 keV (already proven by Belle I)
- width measurement in $X(3872) \to J/\psi\gamma$
  expected yield N$\simeq$350 in 2020–21
  scaled from Belle, Phys. Rev. Lett. 107(2011)091803
  (factor $\geq$2 more than $X(3872) \to J/\psi\pi^+\pi^-$ at Belle I)
  → monoenergetic photon
  provides 4th constraint
  ($\Delta E/E \sim 2\%$)
  → systematic error on width
  may become $\leq$110 keV



What important knowledge is missing?
$\rightarrow$ Width of X(3872)

upper limit on width (Belle I),
$\Gamma < 1.2$ MeV

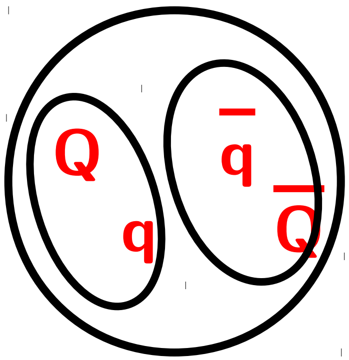
for pure χ_{c1}' charmonium state,
prediction $\Gamma = 40$ keV
G. Y. Chen, J. P. Ma, arXiv:0802.2982[hep-ph], Phys. Rev. D77(2008]097501.

if molecule
- must be larger than width of D*
  Γ > 82.3$\pm$1.2$\pm$1.4 keV
  E. Braaten, arXiv:0711.1854 [hep-ph], Phys. Rev. D77(2008)034019.
- long-range molecular components in the wavefunction?

$\rightarrow$ measure the width of the X(3872)
in the sub-MeV regime

Is the X(3872) exotic ?

TETRAQUARK

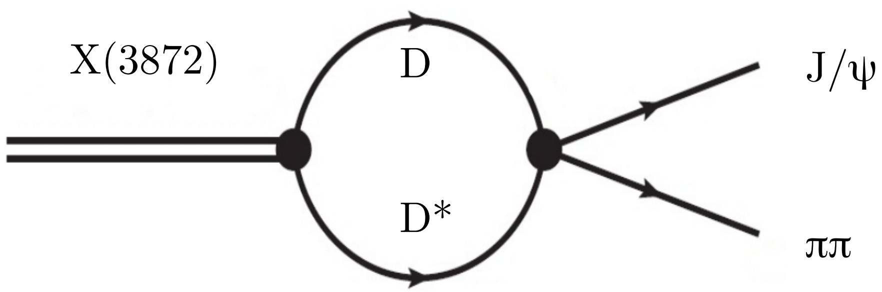


$[qQ]_8[\overline{qQ}]_8$

Diquarks
are colored

Maiani, Riquer, Piccinini, Polosa, Burns;
Ebert, Faustov, Galkin; Chiu, Hsieh;
Ali, Hambrock, Wang

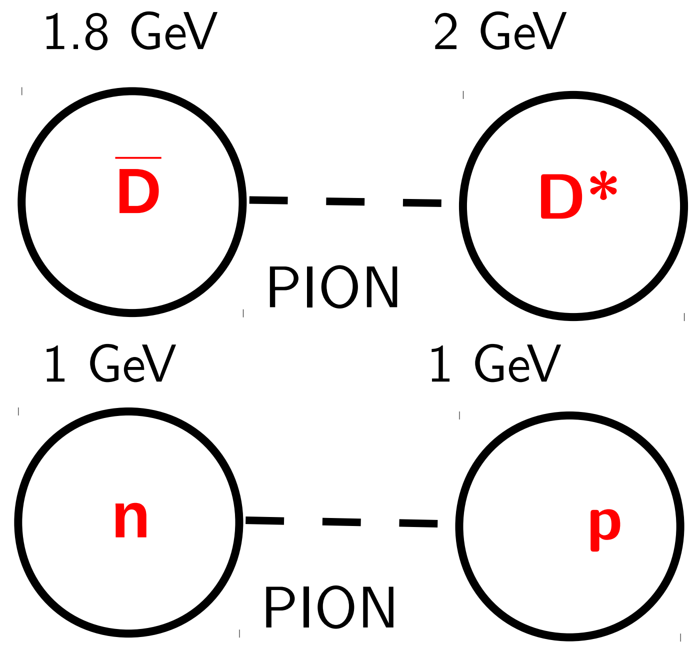
THRESHOLD CUSP



Bugg; Swanson

MOLECULE

Intriguing Analogon

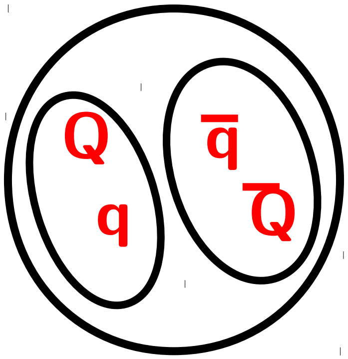


Tornqvist; Swanson; Braaten, Kusonoki,
Wong; Voloshin; Close, Page
Guo, Hanhart, Meissner

Is the Y(4260) exotic ?

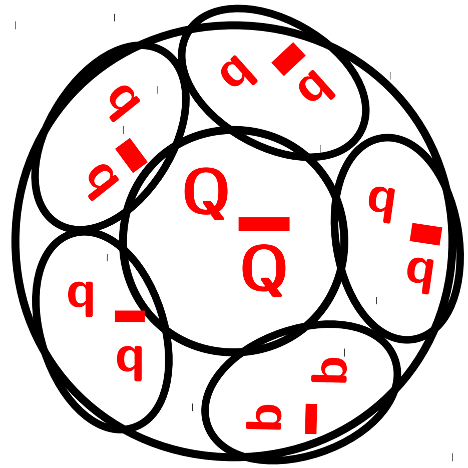
TETRAQUARK

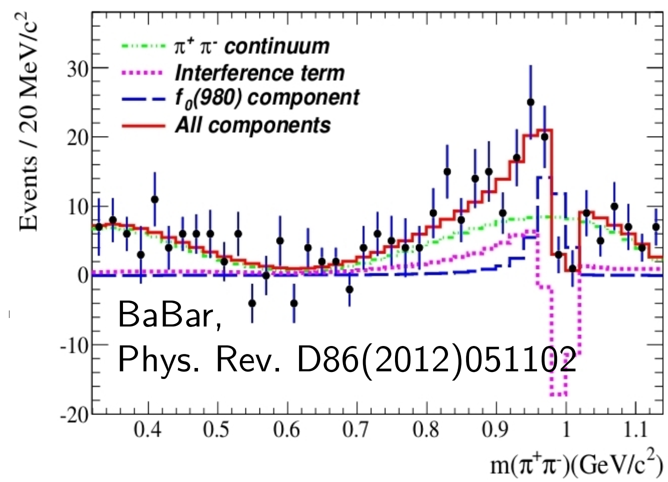
higher excitation ?



Maiani, Riquer, Piccinini, Polosa, Burns

HADRO-CHARMONIUM $[J/\psi\ f_0(980)]$

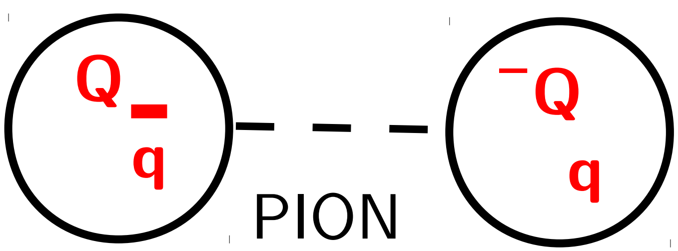




Voloshin, Li
(Guo, Hanhart, Meissner)

MOLECULE

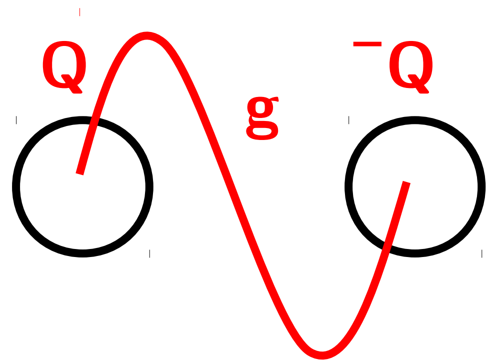
heavier mesons ($\bar{D}D_1(2460)$) ?



[Swanson, Rosner, Close
Guo, Hanhart, Meissner

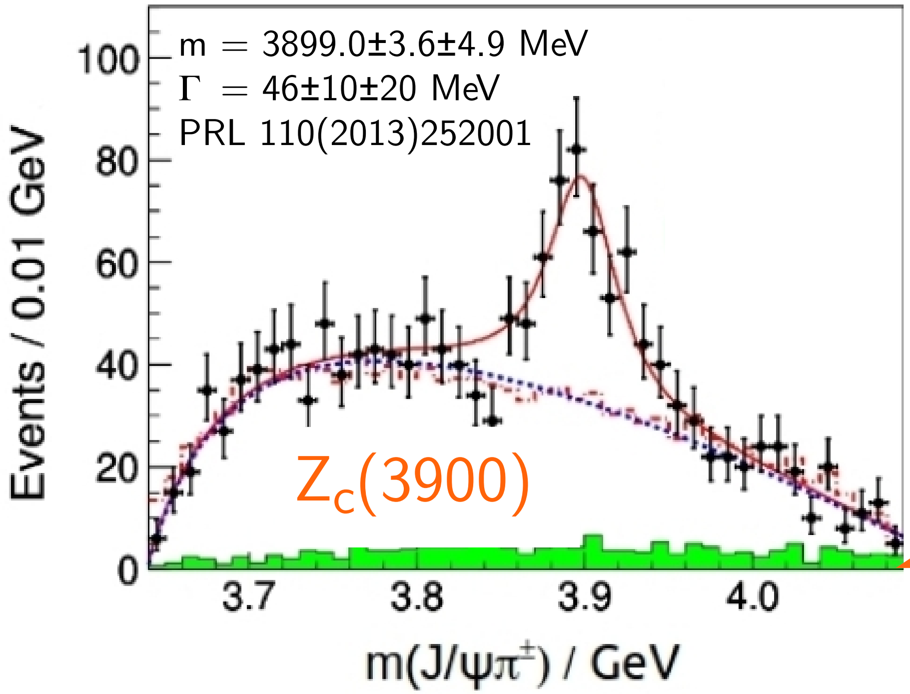
HYBRID

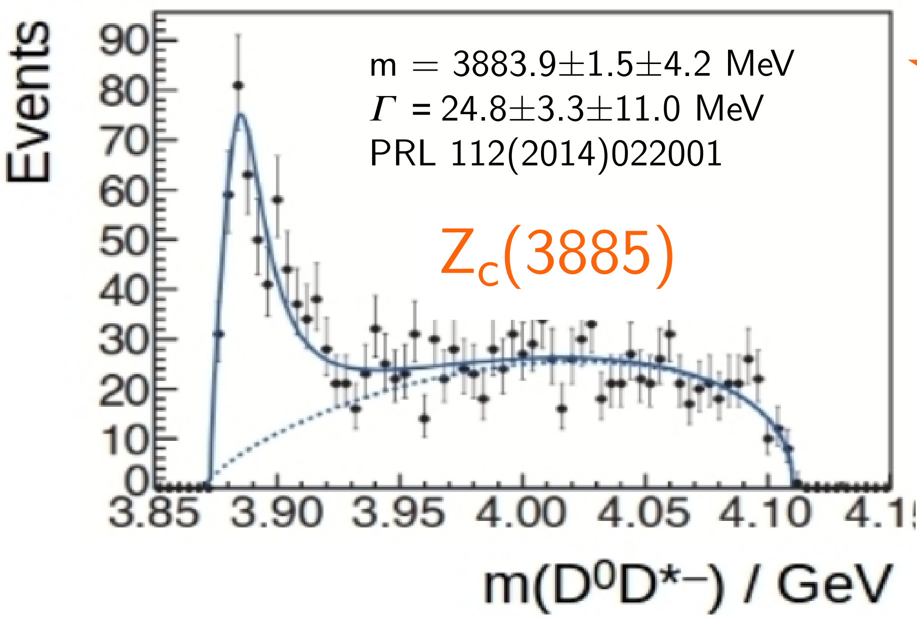
$[Q\bar{Q}]_8 g$



Zhu; Kou, Pene; Close, Page;
Lattice QCD, Bernard et al.; Mei, Luo

Z_c^+ states at BESIII





Decay to $D\bar{D}^*$ dominating
$R = 6.2 \pm 1.1 \pm 2.7$
similar to X(3872)

favors molecule interpretation

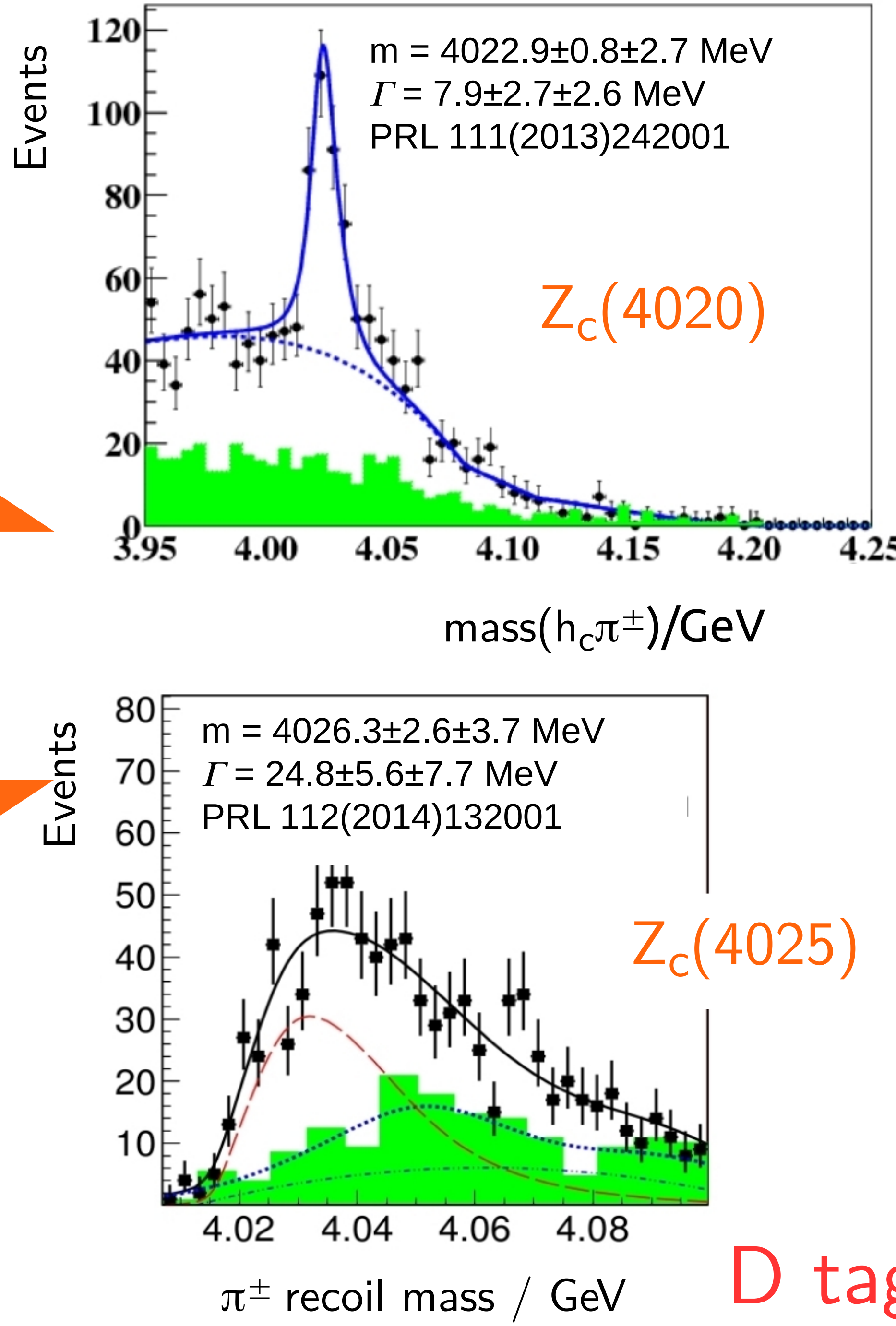
but:
very different from Y(4260) !
(decay to $D^{(*)}D^{(*)}$ suppressed)

although here:
Y(4260) decays !

Z_c^+ states at BESIII

Decay to $D\bar{D}^*$ dominating
$R = 12 \pm 5$

favors molecule interpretation



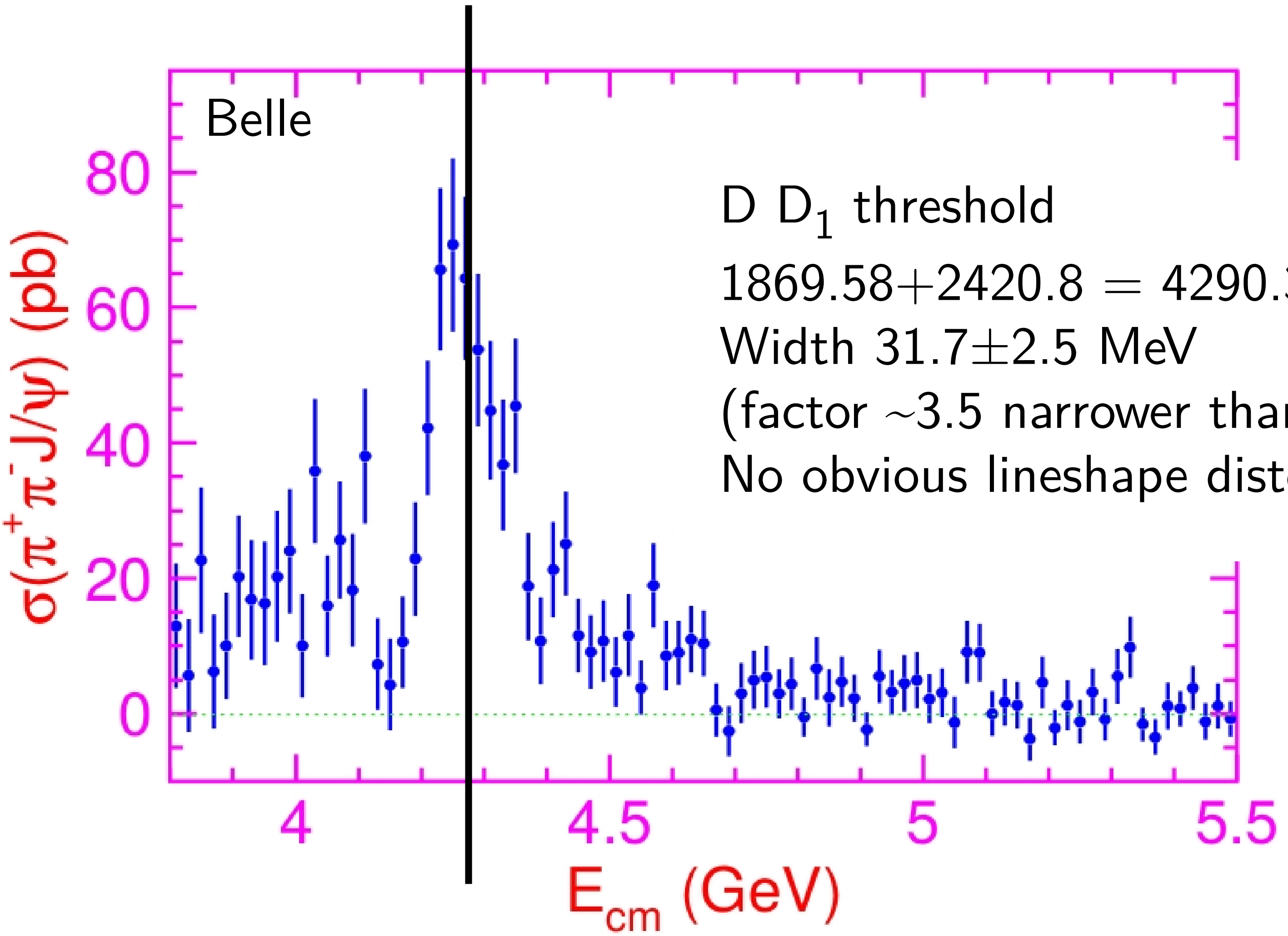
D tag !

Y(4260) Parameters

	BaBar [1]	CLEO-c [2]	Belle [3]	Belle [4]	BaBar [5]	BaBar [6]
$\mathcal{L}$	211 fb^{-1}	13.3 fb^{-1}	553 fb^{-1}	548 fb^{-1}	454 fb^{-1}	454 fb^{-1}
N	125 ± 23	$14.1^{+5.2}_{-4.2}$	165 ± 24	324 ± 21	344 ± 39	–
Significance	$\simeq 8\sigma$	$\simeq 4.9\sigma$	$\geq 7\sigma$	$\geq 15\sigma$	–	–
m / MeV	$4259\pm8^{+2}_{-6}$	$4283^{+17}_{-16}\pm4$	$4295\pm10^{+10}_{-3}$	$4247\pm12^{+17}_{-32}$	$4252\pm6^{+2}_{-3}$	$4244\pm5\pm4$
Γ / MeV	$88\pm23^{+6}_{-4}$	70^{+40}_{-25}	$133\pm26^{+13}_{-6}$	$108\pm19\pm10$	$105\pm18^{+4}_{-6}$	$114^{+16}_{-15}\pm7$

[1] BaBar Collaboration, arXiv:hep-ex/0506081, Phys. Rev. Lett. 95(2005)142001.
[2] CLEO-c Collaboration, arXiv:hep-ex/0611021, Phys. Rev. D74(2006)091104.
[3] Belle Collaboration, arXiv:hep-ex/0612006.
[4] Belle Collaboration, arXiv:0707.2541[hep-ex], Phys. Rev. Lett. 99(2007)182004.
[5] BaBar Collaboration, arXiv:0808.1543[hep-ex].
[6] BaBar Collaboration, arXiv:1204.2158[hep-ex], Phys. Rev. D86(2012)051102.

Y(4260), THRESHOLD EFFECT?



D D_1 threshold

1869.58+2420.8 = 4290.38

Width 31.7±2.5 MeV

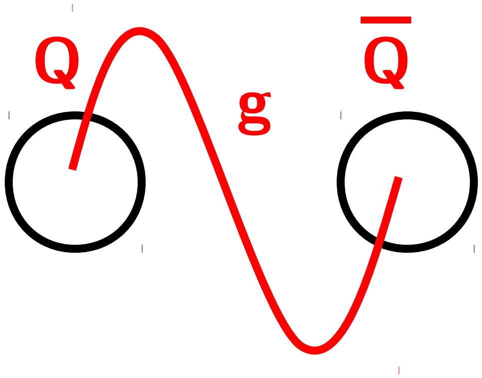
(factor ~3.5 narrower than peak)

No obvious lineshape distortion.

	BaBar [1]	CLEO-c [2]	Belle [3]	Belle [4]	BaBar [5]	BaBar [6]
$\mathcal{L}$	211 fb^{-1}	13.3 fb^{-1}	553 fb^{-1}	548 fb^{-1}	454 fb^{-1}	454 fb^{-1}
N	125±23	$14.1^{+5.2}_{-4.2}$	165±24	324±21	344±39	–
Significance	$\simeq 8\sigma$	$\simeq 4.9\sigma$	$\geq 7\sigma$	$\geq 15\sigma$	–	–
m / MeV	$4259\pm8^{+2}_{-6}$	$4283^{+17}_{-16}\pm4$	$4295\pm10^{+10}_{-3}$	$4247\pm12^{+17}_{-32}$	$4252\pm6^{+2}_{-3}$	4244±5±4
Γ / MeV	$88\pm23^{+6}_{-4}$	70^{+40}_{-25}	$133\pm26^{+13}_{-6}$	108±19±10	$105\pm18^{+4}_{-6}$	$114^{+16}_{-15}\pm7$

[1] BaBar Collaboration, arXiv:hep-ex/0506081, Phys. Rev. Lett. 95(2005)142001.
[2] CLEO-c Collaboration, arXiv:hep-ex/0611021, Phys. Rev. D74(2006)091104.
[3] Belle Collaboration, arXiv:hep-ex/0612006.
[4] Belle Collaboration, arXiv:0707.2541[hep-ex], Phys. Rev. Lett. 99(2007)182004.
[5] BaBar Collaboration, arXiv:0808.1543[hep-ex].
[6] BaBar Collaboration, arXiv:1204.2158[hep-ex], Phys. Rev. D86(2012)051102.
[7] Belle SVD Group, R. Abe et al., Nucl. Instr. Meth. A478(2002)296.

Y(4260), blocked decays



BaBar, Phys.Rev. D79, 092001(2009)

$$\frac{\mathcal{B}(Y(4260) \to D^* \bar{D})}{\mathcal{B}(Y(4260) \to J/\psi \pi^+ \pi^-)} < 34$$

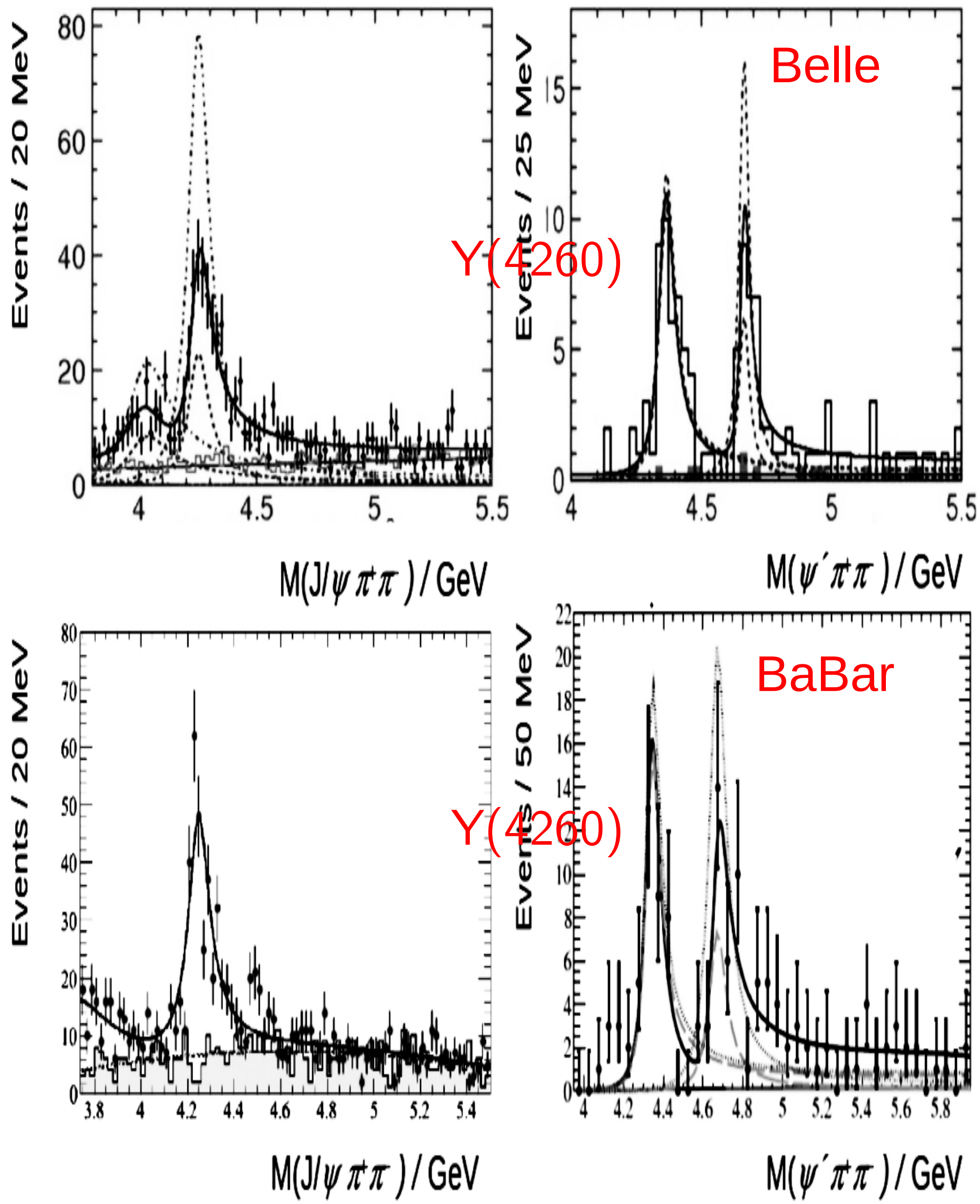
$$\frac{\mathcal{B}(Y(4260) \to D^* \bar{D}^*)}{\mathcal{B}(Y(4260) \to J/\psi \pi^+ \pi^-)} < 40$$

BaBar, Phys.Rev.D76:111105,2007

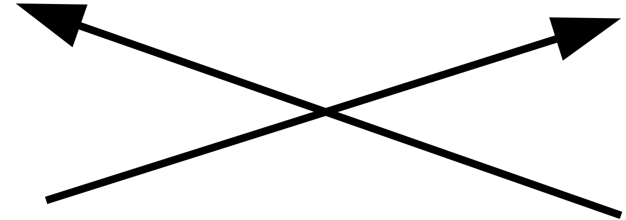
$$\frac{\mathcal{B}(Y(4260) \to D \bar{D})}{\mathcal{B}(Y(4260) \to J/\psi \pi^+ \pi^-)} < 7.6$$

- Y(4260) $\to$ e+e– not observed
  $\mathcal{B}$(J/ψπ+π−) x $\mathcal{B}$(e+ e−) = (7.5±0.9±0.8) eV
  BaBar, arXiv:0808.1543
  $\to$ factor 10^2 smaller than ψ'
- Y(4260) $\to$ $D^{(*)}\overline{D}^{(*)}$ not observed
  $\to$ factor ~60 smaller than ψ(3770)
  (but much larger phasespace)
- $\to$ hybrid ?
  e.g. DD p-wave decay
  „spatial sum rule"
  c and $\bar{c}$ are spatially separated
  can not couple to L=1

Y(4260) – different background ?

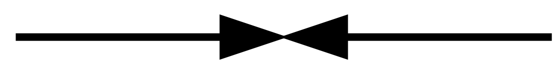


crossing angle
± 11mrad



(83 mrad in Belle II)

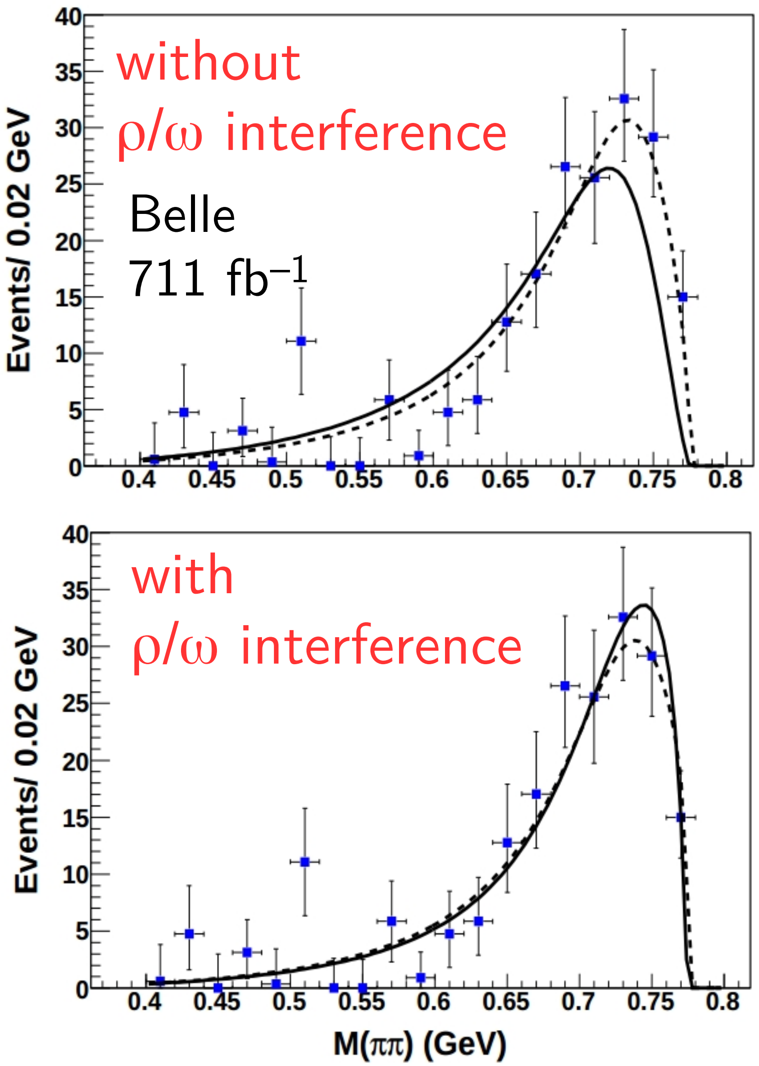
head-on collisions



X(3872), isospin ?

Belle, Phys Rev D84(2011)052004

- almost no non-resonant 3-particle phasespace component
  2 particle decay (back-to-back)
- dominated by ρ^0 ($\sim$100%)
  <u>ISOSPIN VIOLATING</u>
- only two similar decays known in charmonium $\mathcal{B}\sim 10^{-3}$
  but branching fraction of
  $\mathcal{B}(X(3872) \to J/\psi\rho)$
  is order of $\sim$10%
  factor $\sim 10^2$ too large



ρ/ω interference can explain lineshape.

(proposed by Terasaki, Prog. Theor. Phys. 122(2010)1285)

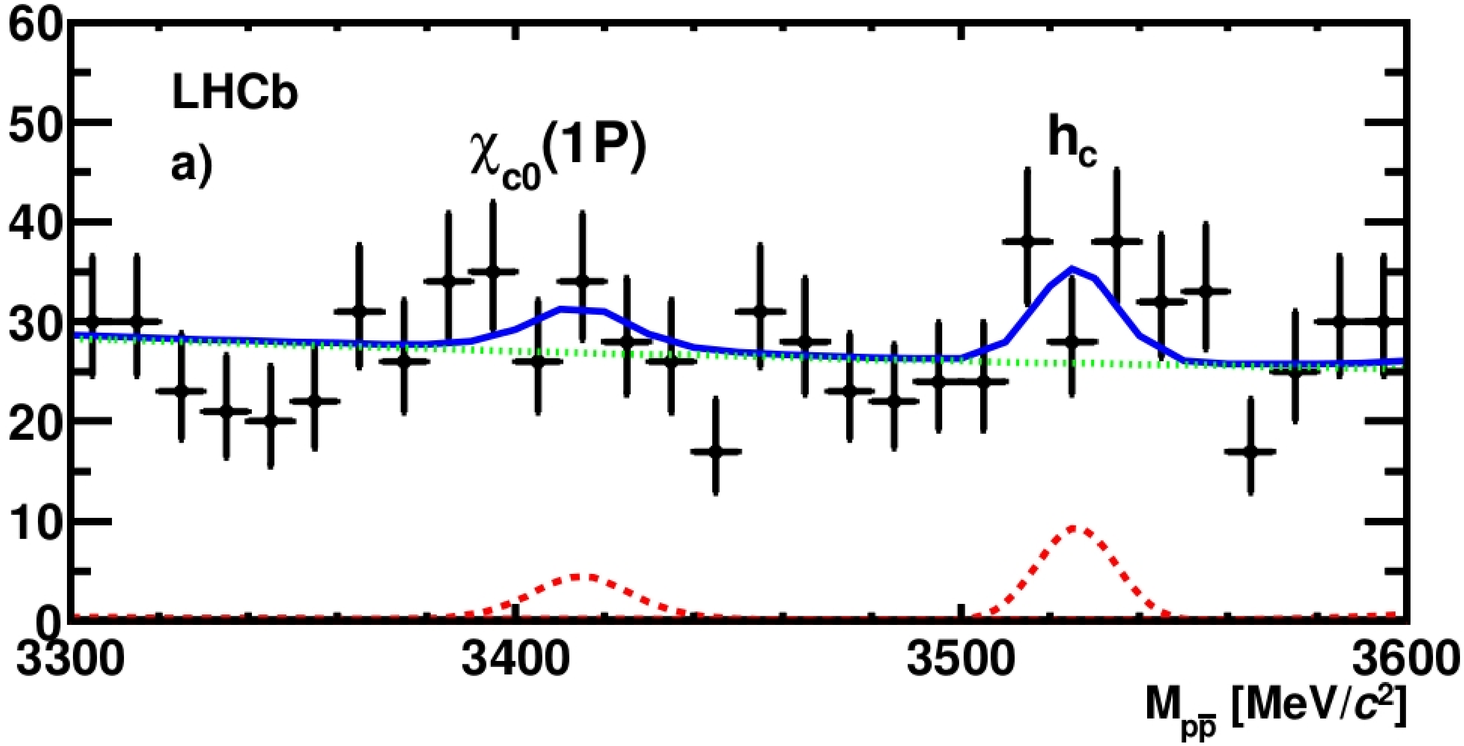
$\to$ X(3872) does not „contain“ isospin

Yield 21+-11 (<40.2) for h_c

→ Panda 1.47±0.86 μb (our value, by detailed balance)

1 x 10^{31} → 0.864 pb^{-1} per day → (1.27±0.74) M events per day

LHCb, 1303.7133[hep-ex], Eur.Phys.J. C73 (2013) 2462



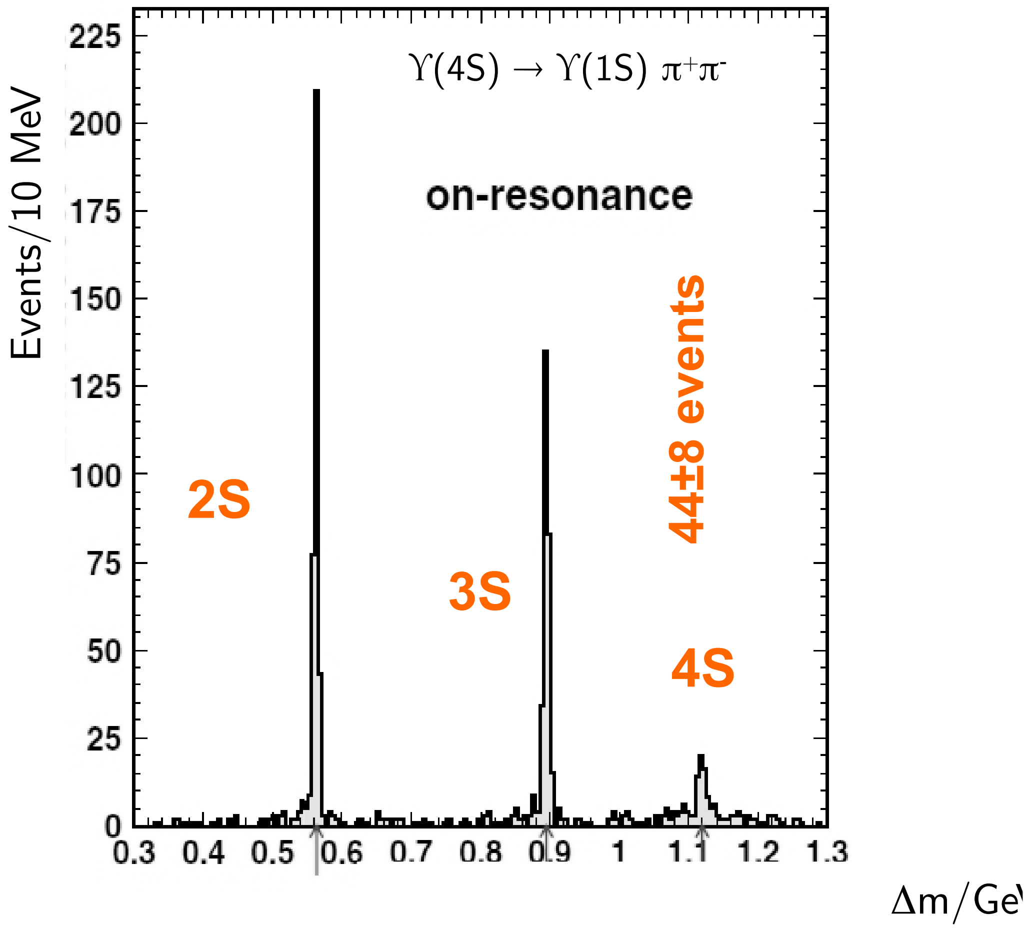
$1/(m_X^2 - 4\ m_p^2)$ in numerator

increases cross section for smaller m_X

→ more yield than X(3872)

Γ [Υ(5S) → Υ(nS) $\pi^+ \pi^-$] is huge

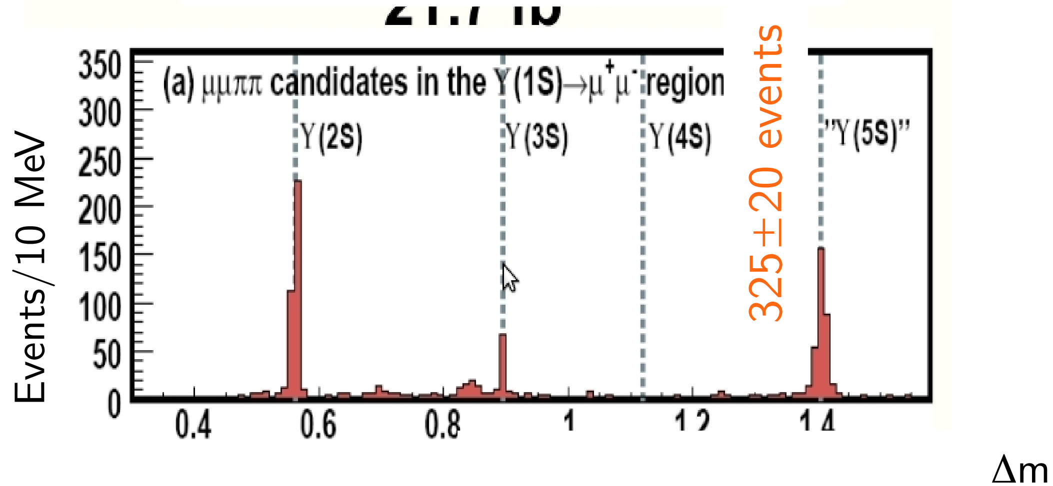
Υ(4S) → Υ(nS) $\pi^+\pi^-$
477 fb^{-1}



Phys. Rev. D75(2007)071103

≅1/20 data
≅1/10 cross section
but factor ≥8 more events
enhanced by factor ≥10^3 !

Υ(5S) → Υ(nS) $\pi^+\pi^-$
21.7 fb^{-1}

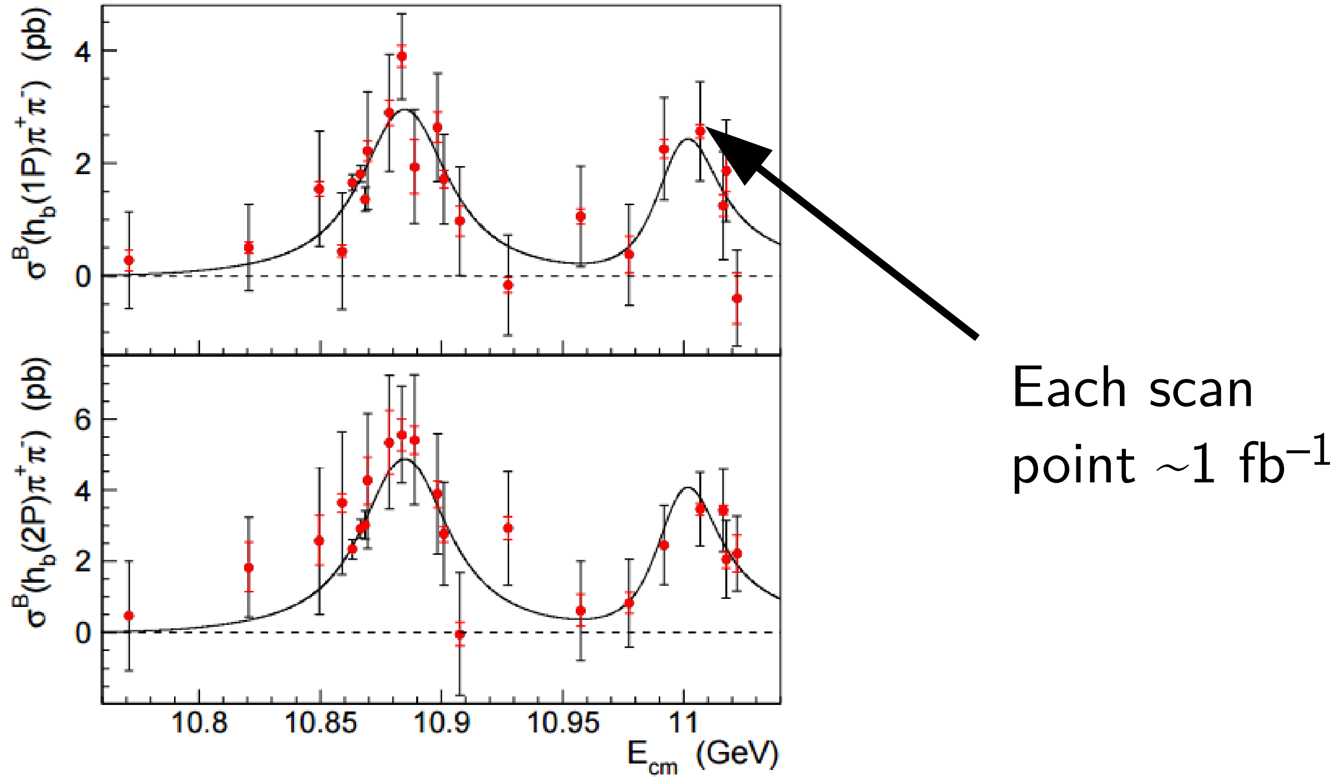


Belle Phys. Rev. Lett. 100, 112001 (2008)

→ Υ(5S) appears exotic itself !

Y(6S) at Belle II

Belle, Phys. Rev. Lett 117 (2016) 142001



Y5S is maybe exotic itself (B(Y(5S) $\rightarrow$ Y(nS)$\pi\pi$) factor 1000 too high)

Y5S not observed (yet) at LHCb

plan: take data at Y(6S) 11020 in phase II (02-06/2018'), 20+-20 fb^{-1}

Is Y(6S) exotic, maybe BB**(0–1+) or B*B**(1–1+) molecule ?

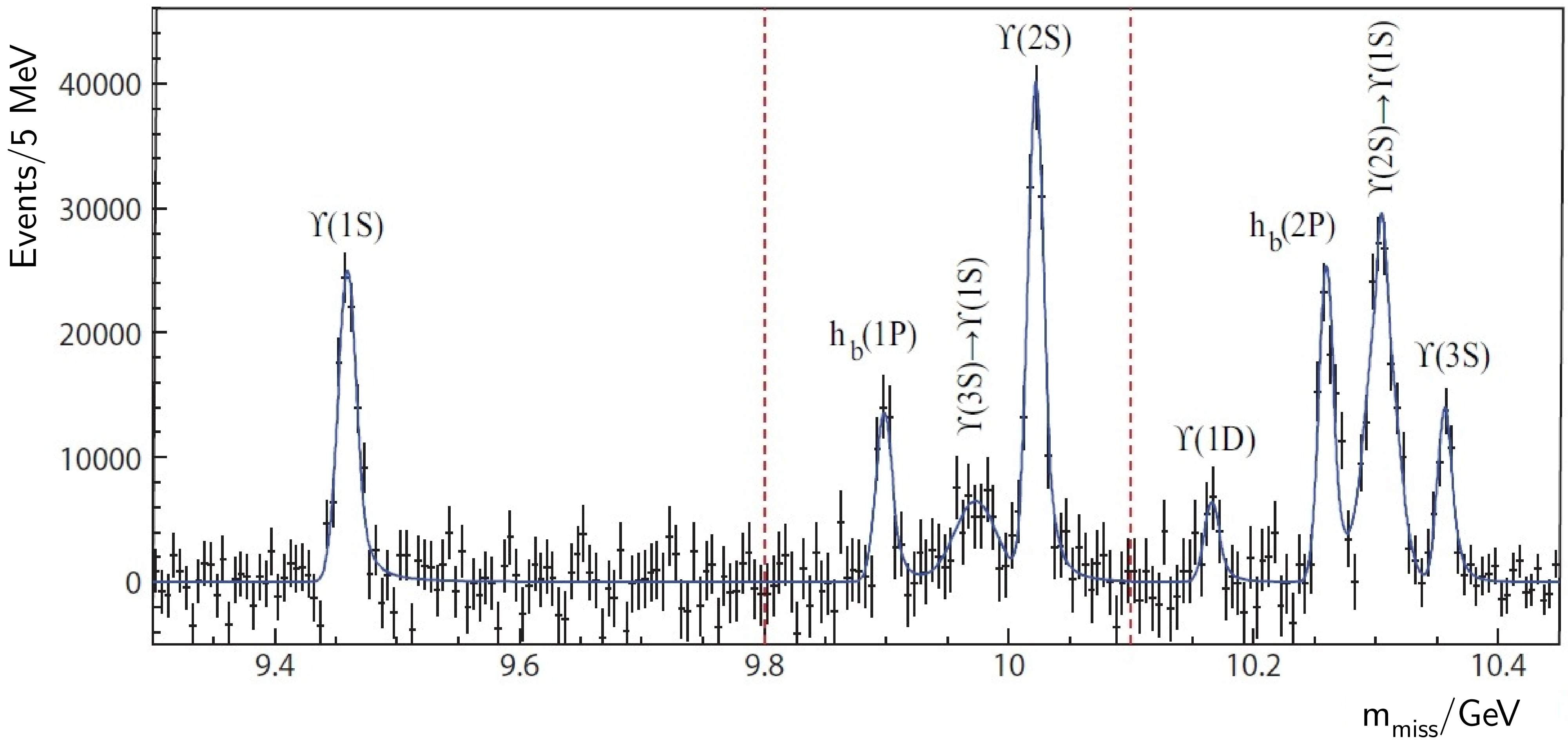
for details see Bondar, Mizuk, Voloshin, Mod. Phys. Lett. A32 (2017) 1750025

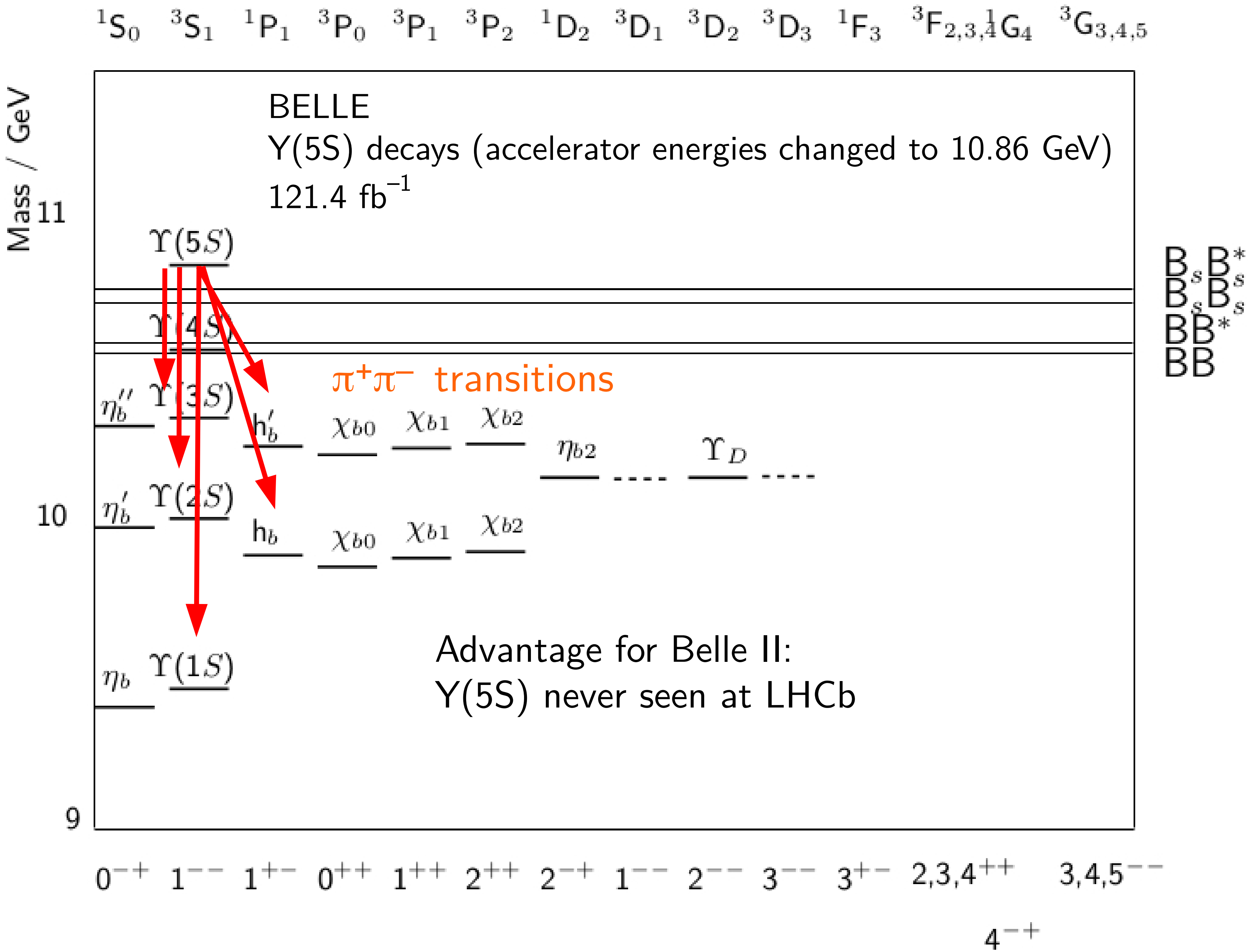
Υ(5S) Decays

$\pi^+ \pi^-$ missing mass

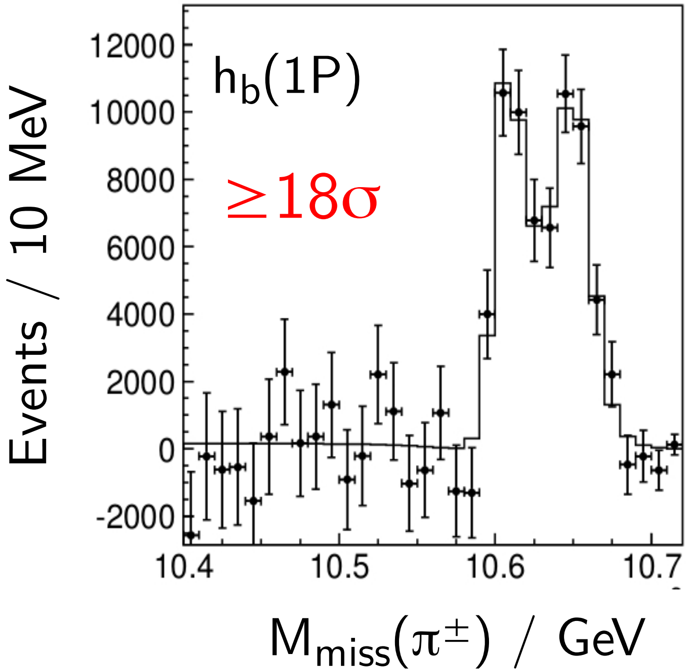
First observation of $h_b(1P)$ and $h_b(2P)$

Belle, 121.4 fb^{-1}
Phys. Rev. Lett 108(2011)032001
arXiv:1103.3419[hep-ex]




BELLE
Y(5S) decays (accelerator energies changed to 10.86 GeV)
121.4 fb^{-1}
$\pi^+\pi^-$ transitions
Advantage for Belle II:
Y(5S) never seen at LHCb
Mass / GeV
11
10
9
$^1S_0$ $^3S_1$ $^1P_1$ $^3P_0$ $^3P_1$ $^3P_2$ $^1D_2$ $^3D_1$ $^3D_2$ $^3D_3$ $^1F_3$ $^3F_{2,3,4}$ $^1G_4$ $^3G_{3,4,5}$
$\Upsilon(5S)$
$\Upsilon(4S)$
$\Upsilon(3S)$
$\Upsilon(2S)$
$\Upsilon(1S)$
η_b''
η_b'
η_b
h_b'
h_b
χ_{b0} χ_{b1} χ_{b2}
η_{b2}
Υ_D
$B_sB_s^*$
B_sB_s
BB^*
BB
0^{-+} 1^{--} 1^{+-} 0^{++} 1^{++} 2^{++} 2^{-+} 1^{--} 2^{--} 3^{--} 3^{+-} $2,3,4^{++}$ $3,4,5^{--}$
4^{-+}

$$e^+e^- \to \Upsilon(5S) \to \underbrace{h_b(mP)\pi^\pm}_{\text{resonant state?}} \pi^\mp$$



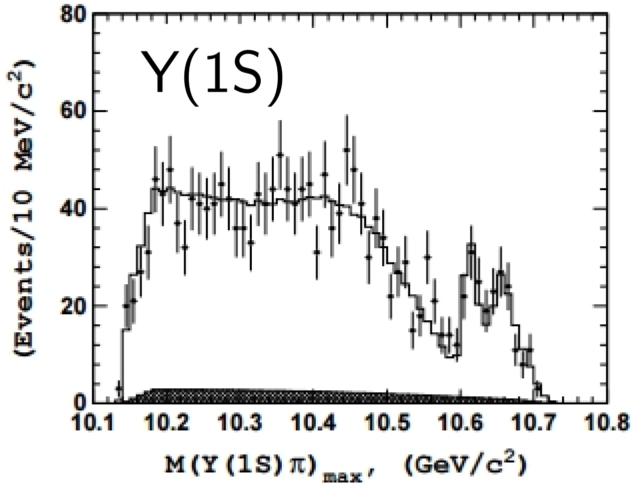
Belle, Phys. Rev. Lett 108 (2012) 122001
Belle, Phys. Rev. D 91, 072003 (2015)

$J^P=1^+$

preferred for both
(other J^P rejected by $\geq 6\sigma$)

$Z_b(10610)^\pm$ m=10607.2±2.0 MeV , Γ=18.4±2.4 MeV
2.6 MeV above $\bar{B}B^*$ threshold
$Z_b'(10650)^\pm$ m=10652.2±1.5 MeV , Γ=11.5±2.2 MeV
2.0 MeV above $\bar{B}^*B^*$ threshold
confirmed in 5 decay modes

HOW MUCH RESONANT Z_b ?

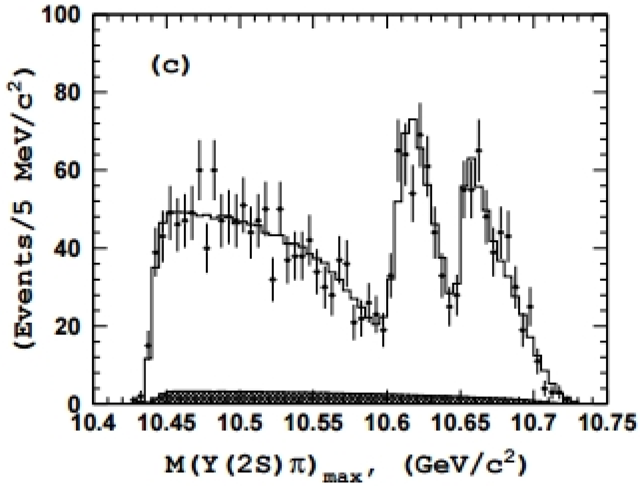


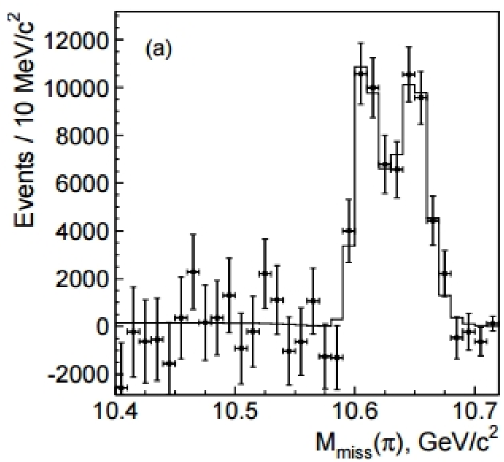
Υ(2S)

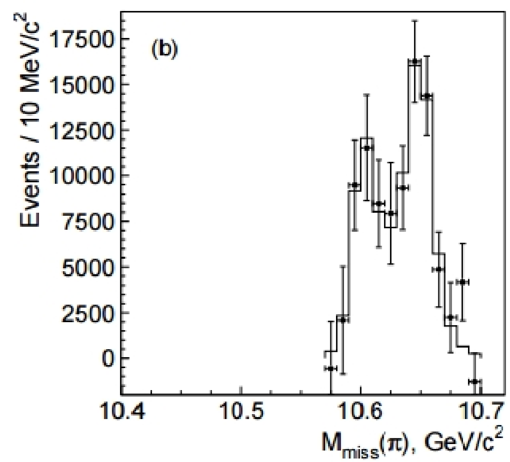
SPIN-FLIP !

SPIN-FLIP !

Υ(3S)

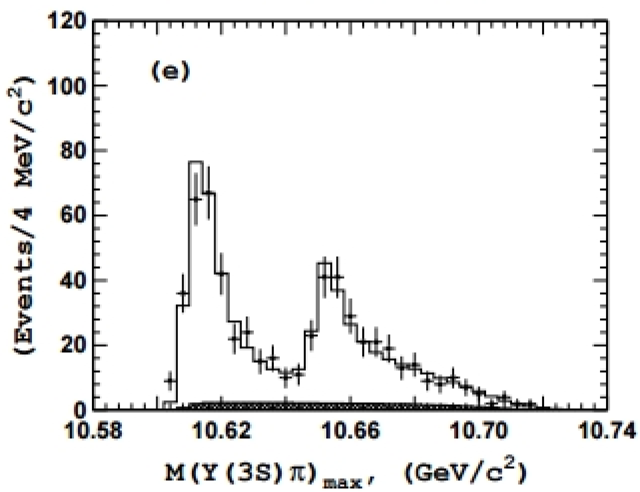






hb(1P)

hb(2P)



Phasespace increases

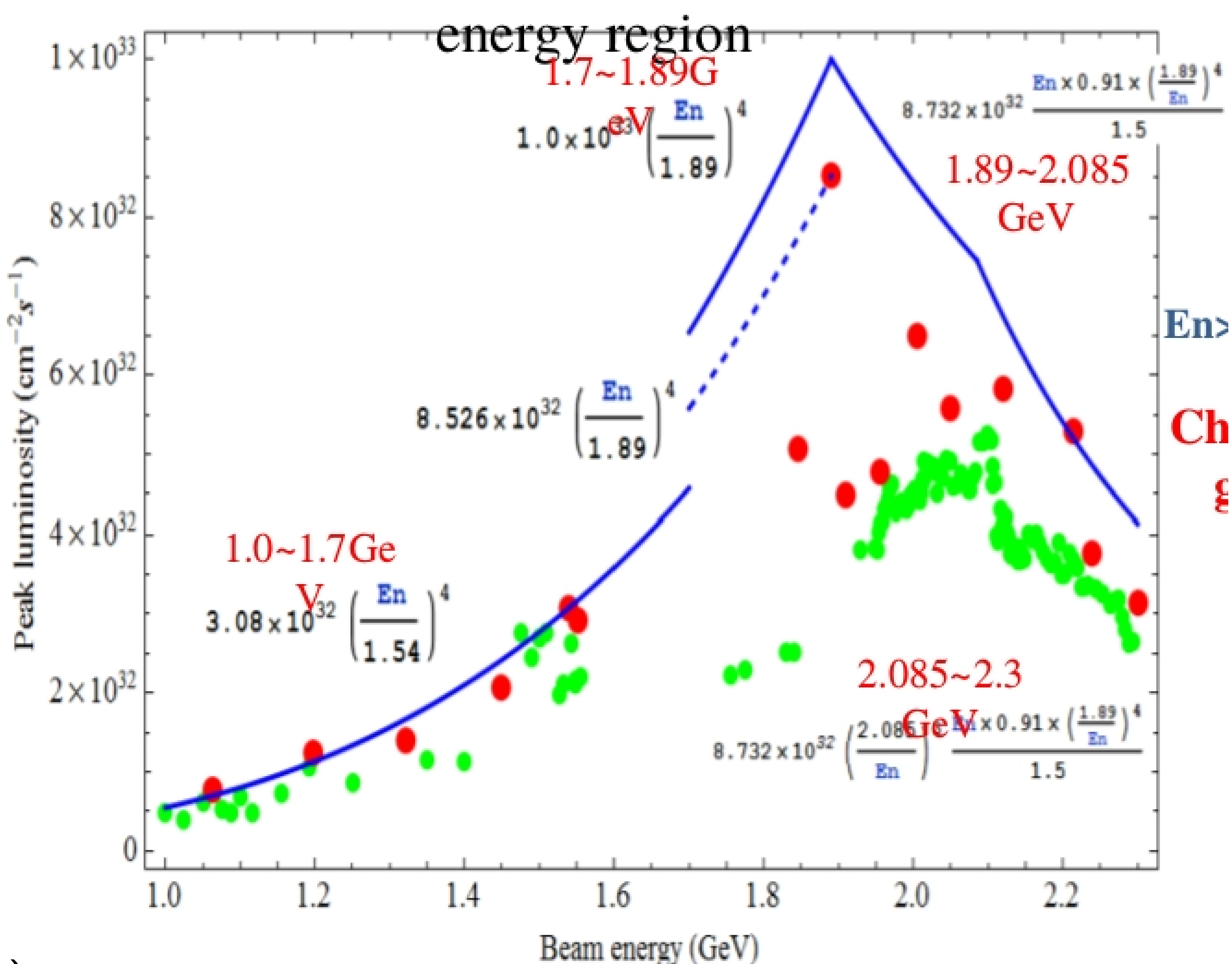
but non–resonant fraction decreases

Compare $Y(4260) \rightarrow Z(3930)$

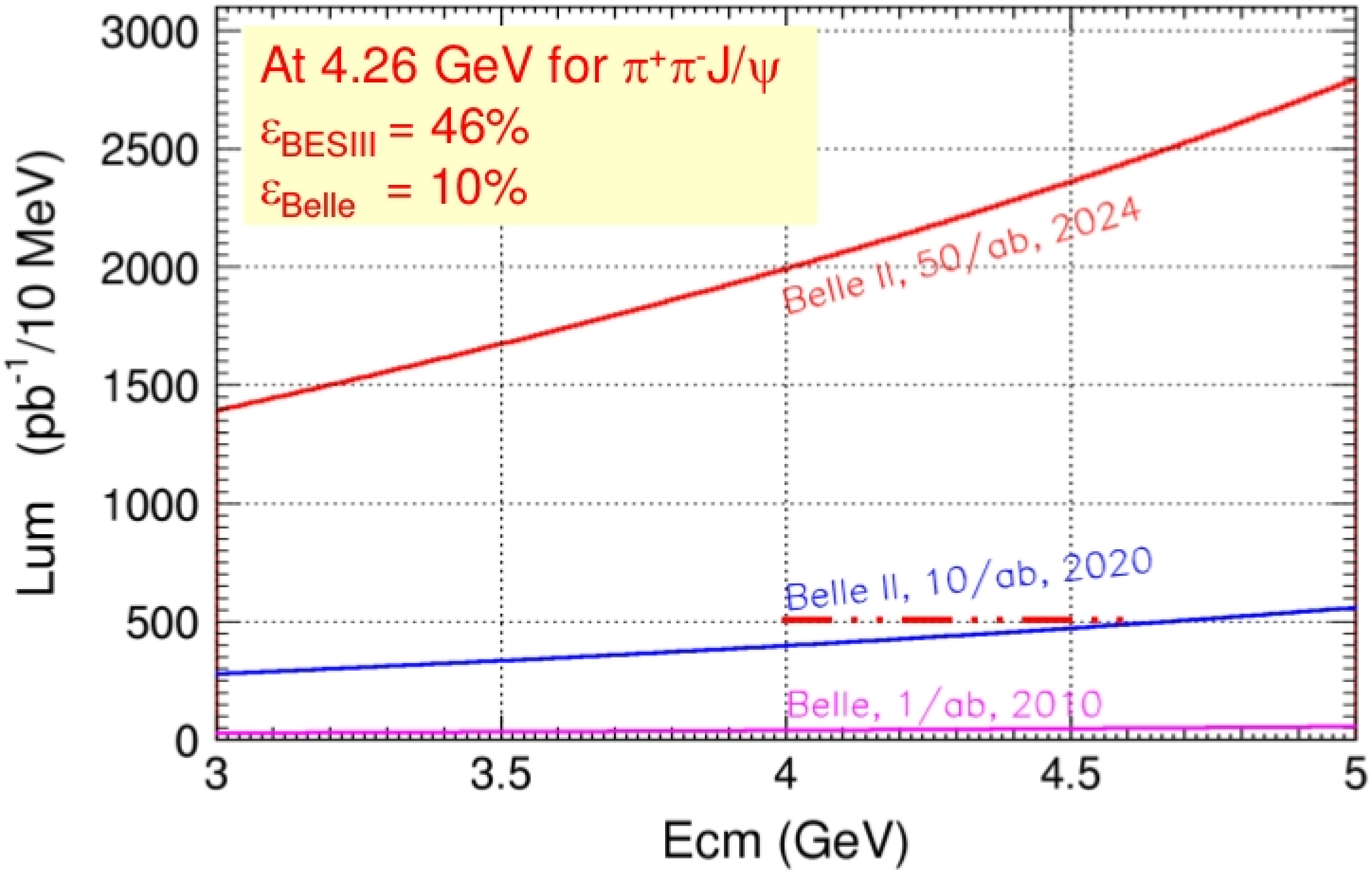
21.5% resonant

BESIII, Phys. Rev. Lett. 110 (2013) 252001

Estimate of peak luminosity at BESIII



Kai Zhu (IHEP)
4th workshop on the XYZ particles
2016Nov. 23-25



Kai Zhu (IHEP)
4th workshop on the XYZ particles
2016Nov. 23-25

Reminder:
Y(4260) not seen at hadron machines